AUG 8 1922

Subscription Price:
United States and Canada, $6.00 Per Year.
Great Britain, 30 Shillings; Single Copies, 4 Shillings.
Foreign, $6.00 Per Year; Single Copies, 75 Cents.

VOLUME IV AUGUST, 1922 NUMBER 4

THE JOURNAL OF INDUSTRIAL HYGIENE

AND ABSTRACT OF THE LITERATURE

EDITOR, UNITED STATES
DAVID L. EDSALL, M.D., S.D.

HONORARY CONSULTING EDITOR
THOMAS M. LEGGE, M.D., D.P.H.

EDITOR, GREAT BRITAIN
E. L. COLLIS, M.D., M.R.C.S.

The Industrial Hygiene of Fur Cutting and Felt Hat Manufacture

Time and Motion Study

Tuberculosis as It Affects the Industrial Worker

Certain Aspects of the Problem of Zinc Toxicity

PUBLISHED MONTHLY BY HARVARD MEDICAL SCHOOL

EDITORIAL OFFICE : : : : 240 LONGWOOD AVENUE, BOSTON 17, MASSACHUSETTS
BUSINESS OFFICE : : : : 66 SEAVERNS AVENUE, BOSTON 30, MASSACHUSETTS

Entered as second-class matter, at the Post Office at Boston, Mass., under Act of March 3, 1879. Published Monthly.
Copyright, 1922, by Harvard Medical School.

EDITORS

United States
DAVID L. EDSALL, M.D., S.D.

Great Britain
E. L. COLLIS, M.D., M.R.C.S.

HONORARY CONSULTING EDITOR

THOMAS M. LEGGE, M.D., D.P.H.

ASSOCIATE EDITORS

United States

W. IRVING CLARK, JR., M.D.
ALICE HAMILTON, A.M., M.D.
EMERY R. HAYHURST, A.M., Ph.D., M.D.
YANDELL HENDERSON, Ph.D.
WILLIAM H. HOWELL, Ph.D., M.D., Sc.D., LL.D.
FREDERIC S. LEE, A.M., Ph.D., LL.D.
HARRY E. MOCK, M.D.
J. W. SCHERESCHEWSKY, M.D.
C.-E. A. WINSLOW, M.S., A.M., Dr.P.H.

Great Britain

W. F. DEARDEN, M.R.C.S., D.P.H.
SIR KENNETH GOADBY, K.B.E., M.R.C.S., D.P.H.
LEONARD HILL, M.B., F.R.S.
T. LISTER LLEWELLYN, B.S., M.D., M.I.M.E.
SIR THOMAS OLIVER, M.D.
R. PROSSER WHITE, M.D., M.R.C.S.
H. M. VERNON, A.M., M.D.
D. A. COLES, M.D.

South Africa

W. WATKINS-PITCHFORD, M.D., F.R.C.S.

Canada

J. J. R. MACLEOD, M.B.

Australia

H. W. ARMIT, M.R.C.S., L.R.C.P.

MANAGING EDITORS

CECIL K. DRINKER, M.D.
MARION C. SHORLEY, A.B.

THE JOURNAL OF INDUSTRIAL HYGIENE

PUBLISHED MONTHLY

VOLUME IV AUGUST, 1922 NUMBER 4

THE INDUSTRIAL HYGIENE OF FUR CUTTING AND FELT HAT MANUFACTURE*

ALICE HAMILTON, M.D.

Assistant Professor of Industrial Medicine, Harvard Medical School

INTRODUCTION

THE making of felt is centuries old. Oriental shepherds are supposed to have discovered accidentally the felting property of wool when subjected to heat and moisture and gentle pressure. It was known to the Greeks; Pliny says the Gauls made a felt so strong that it would resist a sword stroke, especially if they used vinegar in making it. Saxon writers mention "fellen haets." According to the legend, St. Clement the Roman, patron of the hatters, once on a pilgrimage lined his sandals with wool to ease his feet and found that the heat and sweat and pressure had formed a sandal of felt. For long ages the primitive method of making felt hats persisted and may be seen even now in China. Fur, cut from the skin by hand and blown up into the air by the vibrations produced by striking a bowstring, fell over a cone-shaped form and was covered and pressed with a wet cloth. These processes now are carried on by machines, almost all of American invention, and so to a certain extent are the subsequent processes of shrinking and hardening the felt and shaping and smoothing the hat, although hand work still persists in some of the most modern factories where it is held that no machine can take the place of the trained hand of the sizer or blocker or pouncer.

The features that have given to the felt hat industry its reputation as one of the worst of the "dangerous trades" are the presence of great quantities of fine fur in the air of workshops and the use of acid nitrate of mercury as an aid in the felting of fur.[1] The fine hairs which form the fur of rabbits' skin and of the skin of hares, muskrats, beavers, etc., are smooth, resilient, and straight. Treatment with some chemical which makes them limp, twisted, and rough greatly aids in the felting process, and many chemicals have been shown to produce such an effect. Among them is the acid nitrate of mercury now used in the preparation of hatters' fur in all countries, with the possible exception of Russia.

*This is the first of a series of six articles, which are to appear in THIS JOURNAL, dealing with various phases of felt hat manufacture. Received for publication Feb. 28, 1922.

[1] The making of wool felt is not accomplished by the use of nitrate of mercury and is not included in this study.

This method has rooted itself deeply in the industry during more than two centuries. It has been traced back to the middle of the seventeenth century when it was a secret in the hands of a few French workmen, evidently Huguenots, for at the revocation of the Edict of Nantes in 1685, when the Huguenots fled to England, they carried the secret with them, established the trade there, and for almost a century thereafter the French were dependent on England for their felt. In France the fluid was called and is still called *le secret*, the process *sécrétage*, the workers *sécréteurs*, but in English-speaking lands the words carrot, carrotting, and carrotters are used because when white skins are thus treated and heat-dried they take on a carrot color. The formula used is still more or less a secret, although probably the proportions of mercury and nitric acid do not vary much. The French formulae, some of which are used also in this country, are said to call for the addition of white arsenic, As_2O_3, and of mercuric chloride. Arsenic has also been found in the water of a sizing kettle in England. The trade is classed as dangerous above the average in European countries and bears an especially bad reputation in France, Belgium, and Russia.

This report is the first of a series of articles describing an investigation of the hatters' furriers' trade and of the making of felt hats in the United States and in Europe—an investigation undertaken by the Division of Industrial Hygiene of the Harvard Medical School in 1921 and 1922.[2] The felt hat industry is a very important one in the United States and several fairly extensive studies have been made of conditions in American workshops and of the health of the men and women employed. The earliest studies were made in New Jersey in 1860, 1878, and 1886, and it is the New Jersey Department of Labor, under Commissioner Lewis T. Bryant, which has done the most efficient work in the sanitation of the industry. The establishments in New York, chiefly in and around New York City, have been investigated by the state factory inspection service and more recently by the New York City Department of Health. Finally, the National Civic Federation made a study of industrial mercurialism and in 1912 published a report of 102 cases, the majority of them having their origin in the felt hat industry of Brooklyn, Yonkers, Newark, and Orange.

From the perusal of these reports, especially the two last, one gains the impression that felt hat making is a trade with far more risk of occupational disease than the average, and this impression is strengthened by the attitude of the chief industrial insurance companies, which, as we shall see later, class as undesirable risks a number of groups of workmen in this trade. Yet it is hard to substantiate this impression by visits to the hatting centers and by interviews with employees and with doctors. Danbury, for instance, is practically a single industry town; the physicians there all have hatters among their patients. I interviewed ten physicians who had been in practice from three to thirty-five years and, though their opinions varied, none of them believed that the effects of the trade as now carried on were serious. The workmen with whom I talked had much to say of the unhealthfulness of the trade years ago, but the improvement of late had been so great as to make them feel that the industrial insurance companies were unreasonable in classing them as bad risks.

[2] The work was made possible by the generosity of an anonymous donor.

That mercurialism is a danger in the hatters' trade is denied by nobody, although opinions differ as to its frequency and its seriousness, but concerning the second conspicuous feature of the industry, animal dust, there is most contradictory evidence. Dust, consisting of fine fur particles and sharper, harder hair particles, is present in abundance in the earlier processes and to it is added, in the later stages, fine silicon dust, produced by rubbing the formed hat with emery paper to smooth it. There is no difference of opinion in regard to the harmfulness of the silicon dust, but decided difference with regard to the fur and hair dust, some authorities assuming that it is by its nature harmful and that, therefore, the enormous quantities produced in certain processes must constitute a serious danger, others declaring that they can find no evidence of injury among men and women working in these processes.

With this conflicting evidence before us, it seemed worth while to undertake a thorough study of a typical hatting town and of the men actually employed in the trade. It was hoped at first to include Orange, New Jersey, in the study, but work was so slack there that nothing could be done, and we had to confine ourselves to Danbury, Connecticut. The inquiry, as planned, fell into six branches:

1. Description of the processes of felt hat manufacture and of the conditions in workshops in the United States and in Europe.

2. Industrial diseases of hatters as described in the literature and their prevalence in different countries.

3. Physical examination of typical groups of working hatters with X-ray pictures of their lungs.

4. Examination of dust and vapors in the air collected in different departments.

5. An experimental study of the process of felting in order to see if some non-poisonous compound can be substituted for the acid nitrate of mercury now almost universally used in the preparation of fur for felting.

6. Analyses of fur from different departments in order to discover at which stages there is a loss of mercury, for in this way it will be possible to ascertain the departments in which the risk of mercurial poisoning is greatest.

Description of the Preparation of Fur and of Hat Manufacture

The felt hat industry is divided into three parts, although all three may be carried on in one plant and two very commonly are. First comes fur cutting, which includes the preparation of raw skins for carrotting (treatment with nitrate of mercury), carrotting, drying, brushing, cutting fur from the pelt, sorting the different grades of cut fur, packing it in paper bags, and blowing raw and carrotted fur.

This branch is unorganized and manned very largely by foreigners. It does not require an expensive equipment and many of the fur cutting shops are small and very cheaply built and managed. Sometimes fur cutting includes reclaiming waste fur of all kinds and waste felt from hat factories.

The second branch is hat making or "back shop" or "wet work," which begins with blowing and includes forming, hardening, sizing, and the multitude of processes for shrinking and shaping the felt. It may also include what is called preliminary pouncing—that is, rubbing off hairs with fine sandpaper.

The third branch is hat finishing or

"front shop" or "dry work," which includes dry blocking, shaping, final pouncing, and pressing (finishing), and also stitching, banding, trimming, etc.

In the description of the processes of felt hat manufacture no consideration will be given to any aspect of the work except the hygienic. The different methods are discussed only with regard to their effects upon the health of the men and women who use them, without any consideration of the excellence or inferiority of the product. It may be that the features of Italian, Czecho-Slovak, and British plants, which aroused my admiration, are regarded with contempt by American hatters as producing an inferior felt, but it is the worker who is under consideration in this report, not his product.

It would be unfair to make any general statement about this industry in the United States without qualifying it, for there are always at least a few shining exceptions to every indictment one is forced to bring against the industry as a whole. While fur cutting plants are usually poorly built, crowded, dark, ill-ventilated, and almost incredibly dusty, there are several which are well constructed and well managed and which compare favorably, in every respect, with the best in Europe. This is especially true of a large factory in Philadelphia, where all the branches are carried on under the same roof, and of two in Brooklyn, and one in Danbury. Standards, on the whole, are lower in Connecticut than in New York, and not quite so high in New York as in New Jersey.

Hat making plants require a much larger outlay of capital, they are better constructed and employ a much higher class of labor. Much more ingenuity has been expended in the effort to do away with the sources of danger and of discomfort in this branch, yet the difficulties are great and often they have not been surmounted. It is very common to find the blowing room thick with dust which flies through the air and lodges on every surface, and the forming and sizing departments full of steam, the floors awash, and water dripping from the ceiling. Hat finishing is, on the whole, less troublesome, and conditions in the trimming rooms are usually good—often excellent—but the pressing and pouncing departments are among the most dangerous in the industry, and here the safeguards may be very inadequate.

In comparing American with European plants, one finds that the advantages are not all on one side. French fur cutting has some features better than those in Danbury but at least one which is worse. English hat manufacture is superior to American in one department only—the forming room. The factories that I visited in Italy and in Czecho-Slovakia were vast in construction, especially those in Italy, with more than ample space, so that any air-contaminating substance is greatly diluted. My visits to these factories were made during the great heat of July, 1921, yet I suffered less discomfort than I had in Danbury in April and in May. In both plants cool air was driven into the heated rooms with so strong a draft that it blew one's clothing about. The windows on the sunny sides were covered, either with heavy linen curtains or with Venetian blinds. Steam from boiling kettles and tanks was removed more efficiently than in the great majority of American plants, and the work in the forming rooms was dry and easy while in American plants it is wet and heavy. The drainage of floors in American plants always leaves something to be desired, usually a great deal.

In the Borsalino factory, in Alessandria, the cement floors in the wet rooms are stamped in squares with deep lines so that the feet will catch and not slip, and this permits a much steeper slope to the floor than is possible with smooth cement.

The care of the individual workman has never been a responsibility of the employer in this industry in the United States. It is customary to provide long rubber gloves for the carrotters, but other working clothes, as well as soap and towels, must be provided by the workman. In France, Germany, Great Britain, and Czecho-Slovakia, all men and women who handle fur after it has been carrotted must be furnished full suits of working clothes, including caps, and in Italy, although the law does not require it, I found it done in the Borsalino factory, and in Valera and Ricci's, near Milan. Medical inspection of all workers exposed to mercury is required in these countries, with the exception of Italy. It does not seem to be provided in any American plant.

The description given here is not technical; it deals with the various processes only so far as is necessary in order to demonstrate the unhealthful features, if there are any. For a thorough, expert report on the technical problems of ventilation, steam, fume, and dust prevention or removal, lighting, etc., the reader is referred to the very complete report compiled by Miss Lilian Erskine (1) for the New Jersey Department of Labor, and published in 1915, under the title *Sanitary Standards for the Felt Hatting Industry.* Models of exhausts, hoods, etc., may be seen in the state Museum of Safety in Jersey City.

Fur Cutting

Raw Skins.—The handling of raw fur is filthy work; the odor is very disagreeable and rarely is any effort made to lessen the unpleasantness. The skins are in sleeve form as they come from the trappers who pull them off as one pulls off a glove. They are first dampened, then cut open, cleaned with knives, stretched, cleaned in tumblers with sawdust, or carded with a wire brush, and then the long stiff hairs must be removed for they will not felt. Hand plucking or pulling is considered by far the best way to get rid of these hairs, but it is done on a large scale only in Belgium, and Belgian hand-plucked skins are sold to the trade all over the world. In America, machine plucking is done and the long hairs from beaver and nutria skins are sometimes plucked by hand, but the common method of ridding the skin of hairs is to put it through a shearing machine and cut off as much hair as possible without injuring the fine fur. This shearing may be very dusty, as, for example, in one Brooklyn plant, where the air was choking and the machines, the windows, and all surfaces were thick with dust. On the other hand, this same department in the Mutual Fur Cutting Factory in Danbury was beautifully clean.

It seems to be generally assumed that this fur dust is dangerous and must be removed. In Hückel's factory in Neutitschein, each bench for machine plucking is furnished with an exhaust, and I saw an equally good arrangement in Jonas and Naumberg's plant in Brooklyn. How important it is to remove the fur dust in these raw fur departments it is impossible to say until we know more about the effect of such fur on the respiratory tract.

Carrotting.—The application of mercuric nitrate, or carrotting, comes next and may be effected by hand or by ma-

chine. The hand worker dips a stiff brush into the solution[3] and scrubs it vigorously into the fur side of the skin. The machine operator passes a raw skin under a revolving brush which dips down into the "carrot" and then runs over the fur. There does not seem to be much difference between the two processes unless it be that the hand carrotter is more exposed to fumes. His advantage, however, is not great since, although the machine for carrotting is covered, there is often a fine spray from the brush. The machine operator carrots 5,000 to 6,000 skins a day and piles them up on a bench and on the floor around him; the hand carrotter can finish only about 2,000 a day. The men protect their hands with rubber gloves, their forearms usually with stocking legs, and they often wear a pad of felt or wool over the chest and abdomen.

In the Stetson plant in Philadelphia, there is an excellent carrotting room on the top floor with windows on four sides and in the roof. Both machines and hand work are used and the machines are hooded and provided with suction exhausts. This is not true everywhere and local exhausts are rarely seen on benches for hand carrotting. The best I have seen is in Hückel's factory; the opening, 7 inches high, runs along the back of the bench and a proof that the draft is good is seen in the fine fluff of fur over the wooden grating which protects it. The advantage of a fairly equable climate is seen in one of the French fur cutting plants, where all the carrotting is done in an open courtyard, covered with a glass roof. In our northern states, this would be freezing cold in winter and unbearably hot in summer.

One special kind of carrotting is a bad feature in most plants that use it. This is the carrotting of fur scrap in tanks, often uncovered, then centrifuging off the fluid and spreading the fur about to dry in the open air.

Carrotting fluids differ in different countries and in different factories in the same country. Heucke (2) gives the formula in general use in Germany as follows: mercury, 20 parts; nitric acid, 80 (40-36 Bé diluted to 11 Bé). Yellow carrot has more nitric acid, white more mercury. According to Montagné (Thèse de Paris, 1901) the formula generally used in France for carrotting is mercury, 8 parts; nitric acid, 64 parts; white arsenic and mercuric chloride, each 4 parts; the whole diluted with varying quantities of water. Chaplet (3) says that the French use for white carrot: mercury, 40 gm.; nitric acid (36 Bé), 125 gm.; water, 1 liter. Monti (4) says that the Italians use 32 parts of mercury to 100 parts nitric acid (36 Bé) for white carrot; for yellow, 16 to 20 parts of mercury to the same amount of acid, both diluted with water. The carrot used in New Jersey, according to Miss Erskine, is mercury, 20 to 30 pounds; nitric acid, 100 pounds, diluted with 20 volumes of water. Stetson's procedure is as follows: 19.69 per cent. mercury, 31.79 per cent. nitric acid (58 Bé). This, diluted to 13 Bé results in: mercury, 4.28 per cent., and nitric acid, 6.89 per cent., which is the strength actually used in carrotting.

Drying.—It is in drying that more than half the mercury is said to be lost by vaporizing. Heaps of freshly carrotted skins are carried on men's shoulders to be dried with heat for yellow carrot, or at ordinary temperature for white carrot. Americans use about 80 per cent. of yellow carrotted furs, and 20 per cent. of white, the European procedure being just the reverse. For yellow carrot, the usual way is to dry

[3] Known as the "carrot."

the skins in great "stoves," which are iron-enclosed rooms containing a series of heated shelves; in some factories each shelf has its own long, narrow opening closed with a metal flap. The skins are spread on long trays, then pushed in on the shelves, and after an hour or so drawn out through the narrow opening. This is a good arrangement, much better than wide doors; nevertheless, the great tray of hot skins is undoubtedly a source of mercurial fumes which are breathed, not only by the men who tend the stoves, but often by the carrotters as well, for the stoves are often in the carrotting room. A decidedly worse method is to place the skins on racks and provide the stoves with wide doors through which the racks may be pushed in and pulled out. The best arrangement of all is to be seen in some New Jersey plants. It is essentially an endless wire apron passing slowly along over steam pipes, with a narrow opening for a feed door, an automatic discharge, and an in-draft to prevent the escape of fumes.

White carrot is sometimes dried over the stoves, but usually in a separate room at ordinary temperature, the skins being hung or spread about a large room which sometimes opens into a working room. There seem to be different theories with regard to white carrot. In one plant, air is driven into the room by fans, in another no ventilation is allowed, for it is held that the skins must dry in still air.

Storing.—Before storing, the dried skins must be dampened and this work is often done by women. All who handle the carrotted skins show deep yellow stains on the hands, and it is inevitable that they should inhale volatilized mercury. The storage rooms in which the skins are stacked for varying periods to "ripen," sometimes for many months, are often in the basements of the building and poorly ventilated. The work of the storage room man, filling and discharging the great wooden slatted bins, is regarded as undesirable, even by the most optimistic employer. Storage rooms should be quite shut off from workrooms, but I have seen them opening—and the doors open at the time—into the fur-mixing room, into the brushing room, and in one case storage room and carrotting room were the same. Since wood absorbs mercury, the New Jersey Department of Labor advises against its use in the construction of storage rooms.

Brushing.—Brushing the carrotted skins is usually done by machine. Obviously, from this time on, dust is a much more serious item than it is in the raw skins department, for it is now laden with mercury. The man, or more often woman, brusher, usually works at a bench with a pile of carrotted skins lying on an iron shelf under which is the brush. She holds the skin against two rolls which catch it, carry it over, brush it, and bring it back again to be pulled out. These women have yellow stains on their hands. The dust may be carried off by exhausts if the brush is so arranged that it revolves away from the brusher, and this is sometimes true, but when, as in some factories, it runs toward the brusher the exhaust cannot catch all the dust and a fine fluff can be seen on the face of the brusher, especially on the chin.

Cutting.—The cutting machines are an American invention, very efficient and horribly noisy. This is by far the most trying part of a hat factory to the outsider, for the din made by the machines is almost intolerable. The cutter, almost invariably a man, feeds the skin into the machine which, by means of stationary and rotary knives,

shreds away the pelt and delivers the fur on a flat tray. Women sorters, sitting at a long table in front of the cutter, receive this tray. Their task is to remove bits of skin and tangled fur ("dags"), and then to sort the fur into different grades, the cheeks and feet forming the inferior, the center of the back the superior grade, except in the case of water animals, whose best fur is on the center of the belly. From three to five sorters work with each cutter. This is what is called in England "locking."

The shredded pelt, which looks like excelsior and is known to the trade as "noodles," is gathered up from the floor and, if there is a good deal of fur clinging to it, it is shaken violently, a dusty procedure, which should not be allowed, and which is not necessary because a well-set cutting machine will deliver very clean noodles. The final destination of the shredded pelt is a glue factory.

The fluff in the cutting room is seldom abundant but is very fine and can sometimes be seen on the women's hair or on the caps they usually wear to protect their hair. But conditions in cutting rooms vary greatly in this respect. In the Mutual Fur Cutting Factory in Danbury the sorters are all Syrians, and I could see no dust at all on their shining black hair. Work in the cutting room is not considered as bad as in subsequent departments where steam is a prominent feature, and this impression is doubtless justified since the mercury volatilizes less in the absence of heat.

Storing Fur.—The women sorters weigh the cut fur and pack it in paper bags, which go to the storage room for cut fur, another notorious source of mercury fumes and usually very poorly ventilated. In the plant of Jonas and Naumberg in Brooklyn, great pains have been taken to remove the mercurial fumes by driving in fresh air from above and applying suction exhaust below.

"Blown fur" is reclaimed fur, scraps pasted on paper and put through a cutter. It is mostly raw with a little carrotted fur. Ordinary fur is known as "cut fur," even if it has been already blown. For reclaiming, pieces of fur from garment shops are chopped and blown, "roundings" of felt from hat shops are bleached, chopped, and blown —all of which is dusty work, but largely free from mercury.

Hat Making or "Back Shop"

Mixing.—The fur from the cutting shop is mixed by hand or by machine and then goes to a "devil"—*i.e.*, a cone-shaped box with a fan bringing in a draft of air to blow the fur, and teeth which revolve and pick apart the fur so that the draft can catch it and mix the different varieties together.

Blowing.—This is almost always an excessively dusty process in American plants; indeed, I have seen but four which were fairly dust free. The blower is essentially a series of compartments, usually six, enclosed in fine wire netting and furnished with a travelling apron which feeds in the fur and with rapidly revolving pickers which catch it, pick it apart, and toss it in the current of air formed by their revolutions, letting the heavier hairs and the dust fall to a space between the apron and picker. This air, of course, passes out through the netting, and the amount of fur carried out depends on the rapidity of the revolution of the pickers and also somewhat on the quality of the fur, for if a great deal of short fur and "roundings" — *i.e.*, ground-up felt

trimmings—form part of the mixture, more will escape during the process of blowing. The fur tends to cake or felt over the inner surface of the netting and must be shaken down by beating on the outside, a procedure which is sometimes done by machine, sometimes by hand. It also cakes within the machine and the task of cleaning is very dusty.

Moisture is necessary to keep the fur from clinging together in masses, and this is commonly provided by jets of steam driven into the room through pipes placed at intervals. The combination of steam and choking dust makes the usual American blowing room a trying place. I have seen fur flying about as thickly as snow in a heavy snow storm, and in one Danbury plant the steam and fur had formed a solid felt coating over the windows. In a Brooklyn plant, the dust from the machines was increased by the use of compressed air to blow the accumulation of fur off the top of the apparatus. In such places, the men are covered with fluff—faces, hair, and clothing—and they chew tobacco constantly because the expectoration helps to get rid of the fur in the throat.

The great Stetson plant in Philadelphia has an excellent blowing room. The draft within the blowers is as strong as in other plants, but a heavy oilcloth hood with the glazed side under, curving over the blowers, prevents dust from escaping. Another excellent feature, which I have seen nowhere else except at Stetson's and in the Mutual Fur Cutting Factory in Danbury, is the delivery of steam into the machine instead of into the room, which means that far less steam is needed and that the air in the room is not so unpleasantly humid. In both these factories, mechanical beaters flap continually against the network to dislodge the dust.

European blowing rooms are far less dusty, they are freer from fluff than the best American, and yet the blowers are not covered. It seems to be a question of the rate of revolution of the pickers; the more rapidly they revolve, the greater the air current and the greater the escape of dust. Certainly, the blowing rooms in the English, Italian, and Czecho-Slovak factories which I visited formed a strong contrast to the usual American departments, although none had so good a humidification system as Stetson's and as Buzaid's. In one of the Italian factories, Valera and Ricci at Monza, no humidification at all is used; they do not find it necessary in that warm climate.

The New Jersey Department of Labor believes that humidification is greatly overdone in most factories, that it is quite unnecessary in warm weather, and that the usual 65 to 75 per cent. humidity is needed only in cold weather when the fur is full of electricity.

Forming. — The ingenious machines used for forming in every country are of American invention. Blown fur is weighed by girls into quantities sufficient each for one hat. The girls stand at the back of the former (the machine is known as the former, the operator as the coner), and a traveling belt carries the weighed fur to a great cylinder where it meets a picker which picks it apart. It then meets jets of steam which warm and moisten it; then a strong current of air catches it and sucks it down over a perforated brass cone which is placed on a turn-table in a chamber at the end of the cylinder. This forms an even, loosely compacted layer of felt over the copper cone about three times as large as is desired. The coner opens this chamber—and a puff of dust always escapes as he does so—throws a burlap wrung out of boiling

water over the cone and its delicate fur covering, fits a similar cone over it, lifts them off and plunges them into a tub of boiling water which stands beside the former.[4] This gives the fur cone its first shrinking and it can then be lifted off, wrapped in burlap, and given to the hardener who slips it over hand and arm or spreads it on a bench, examines it for flaws, "stops" the weak places with fur and picks out dags. The hardener then puts about a dozen cones together, sprinkles them, kneads them with his hands for the first hardening and sends them to the sizing room where the 30 to 35-inch cone is gradually shrunk down ("sized") to about one-third and changed from loose delicate felt to a hard, even structure.

The work of the coner is very hot and heavy, and practically incessant. The air, even in the best ventilated rooms, is full of steam and the floor streaming with water. Analyses of the air from the formers have shown the presence of mercury, volatilized by the steam, and to this air are exposed not only the coners but also hardeners and girls employed in weighing batches. These girls are almost always stationed where heat and humidity are worst, right under the ceiling. I was impressed by the arrangement in Borsalino's factory, where the girls weighing batches work in the room above the former, dropping the batches through a small opening, whence compressed air delivers them to the machine below. An electric light signals for each batch.

In one Brooklyn plant, the discomfort in the forming room is increased by driving jets of live steam into the room. The suction inside a former is very great and unless the room is amply large air must be drawn in from another room and, as a usual thing, it is drawn from the sizing room, laden with steam and heat. The humidity may reach saturation, yet it is quite unnecessary. The escape of fluff from the former is always visible and in one badly neglected factory in Danbury the windows of this room are covered with felt.

Forming is less strenuous and far less disagreeable in Europe. The reason is that the hot water, needed to give the cone of delicate felt its first shrinking, is applied within the former by means of a long jet of water which plays evenly over the surface of the revolving come just before it is taken out. Then all the workman has to do is to open the former, gently lift off the cone of felt, fold it together for the inspector, and wait for the next one to form. There is no steaming tank, the floor is dry, there are no heavy brass cones to lift repeatedly, and the work is light and leisurely compared to the same work over here. This method was used in all the foreign plants I visited and was common in this country some twenty years ago. Another good feature was the vast size of these rooms in the European plants, providing air enough for the suction in the former.

Sizing Room.—After being inspected, the cone goes to the sizing room and there is put through a series of processes known as hand starting, wetting down, pulling out, sizing, blocking, wringing or whizzing, etc., all of which are essentially the same, consisting in the application of boiling water and pressure to shrink the felt down to the proper size and then to shape it. Sizing, whether by machine or by hand, is very laborious work and is carried on in an atmosphere of humidity and heat. The hand sizers (sizers may also be called "makers") usually work in

[4] Coners are sometimes divided into coners and "wetters."

groups of eight at an octagonal "battery"—that is, a tank of boiling water with a wooden bench running round it. The sizer first sprinkles several hats with boiling water usually acidulated with a small amount of sulphuric acid, kneads them gently with his hands, then as they harden he works them more vigorously and plunges them into the water, cooling his hands in a pail of cold water. Finally, he takes one hat at a time and beats it with a wooden rolling pin. He usually protects his hand partially by a leather or wooden shield over the palm. This is the work that the English call "planking."

Sizing machines are like large clothes wringers with wodoen rolls obliquely fluted, and the sizer alternately dips a bundle of cones in the tank of boiling water below the rolls and places them between the rolls. The sizing room is full of these boiling kettles and it is rare to find one which is not foggy with steam, water dripping from the ceiling and running in streams on the floor. Curiously enough, the water from the kettles which must be "pulled" twice a day is not emptied through separate drains but is flooded out over the floor to find its way through the gutters to the main drain.

Great efforts have been made in certain factories to control the steam in the sizing room by exhaust ventilation and by control of the temperature, for if the moisture-laden air comes in contact with cold air from open windows it condenses and a thick fog forms. Against a cold ceiling the fog turns to water and rains down on the heads of the men. The problem is excessively difficult in our variable American climate and success has been obtained only in those factories in which adequate exhausts are installed at the place where the steam is generated, for once it has been permitted to escape into the air nothing effective can be done to get rid of it. There is general testimony from the workmen as to a decided improvement in sizing rooms during recent years, but conditions in most of the plants outside New Jersey still seem productive of discomfort and fatigue, if not of mercurial poisoning. For instance, my notes on a Danbury sizing room read as follows:

> As I went into the sizing room I walked into a dense fog. The windows were open, the day was chilly, about 58° F., and as all the boiling tanks are unprotected by hoods, the steam was rising, and when it met the cold from the windows it formed a fog. There are exhausts placed at intervals, supposed to carry off the steam, but I could not see that they did the slightest good. Streams of water were running over the floor, and, although the sizers stand on wooden platforms, they have to step down every now and then into the stream. They were sopping wet, the shirts clinging to their bodies, and water dripped on us from the ceiling. About 100 work here an eight-hour day. It is piece work and the pace is very rapid.

In one Brooklyn factory the sizing kettles are either quite unprotected or provided only with a suction pipe, the opening of which is too narrow to catch much of the steam. In Stetson's factory where a great deal of hand sizing is done, the kettles are very well protected by a circular hood with an exhaust pipe and with a curtain composed of flaps of heavy canvas which hang from the edge of the hood to the edge of the kettle, the sizer pushing the hat under the flap. This admirable arrangement prevents the escape of steam. Hückel's factory has the same arrangement. For sizing machines the devices in the Berg and No-Name factories in Orange are very efficient. A metal hood with an exhaust pipe fits

over the sizing machine, enclosing all of the kettle except for an opening in front just large enough to work through. Very much the same kind of hood is used in Borsalino's factory, and here an excellent feature is the rough cement floor sloping well to the drains and the efficient control of the temperature by big registers in the floor through which delightfully cool air is sent in summer and warm air in winter.

Stiffening.—The majority of hats made in American factories are soft felt but require some stiffening. This process is of no importance from our point of view for the stiffening compound is simply shellac dissolved in hot water, borax, and common salt, rubbed in with a brush, and then steamed to melt the shellac and drive it in. For stiff hats (this word is applied only to derbies) the procedure is different. The hats are first shaved by a machine like a small lawn mower which clips off the ends of those hairs that have escaped the blowing process and become incorporated in the felt. The fine harsh dust of shearing is generally considered decidedly harmful. The stiffening department is usually quite separate because of fire risk from the vapors of alcohol used to dissolve the shellac. Denatured alcohol is used with varying quantities of wood alcohol according to the formula selected, for the revenue law allows from 4 per cent. to 20 per cent. of wood alcohol in the mixture. Up to 1906, straight methyl alcohol was always used for stiffening and it was largely through the efforts of the Danbury hatters, backed by the physicians in Danbury, that the law was passed by Congress providing for revenue-free denatured grain alcohol. This has brought about a vast improvement in the stiffening of felt hats, but it must not be forgotten that denatured alcohol is not free from danger. The addition of as little as 2 per cent. of methyl alcohol has been known to lead to characteristic poisoning (Loewy and von der Heide, 5) and the formula commonly used for stiff hats contains as much as 10 per cent. It is well known among stiffeners that some men cannot stand the fumes even of the denatured alcohol, although others are not affected at all. Drying these hats may be a source of danger for mercury has been found in the course of recovering the alcohol.

Dyeing.—Dyeing may be done at several different stages. For mixed colors the blown fur must be dyed before the cone is formed, but this makes sizing more difficult and is not used for solidly colored hats. A method which is very objectionable to the men has recently been revived in Danbury after many years' disuse. This is known as "mucking" and consists in the addition of the coloring matter to the water in the sizing kettle so that the sizers must work continuously in hot dye. The men say it makes the ends of the fingers sore, that hang-nails inflame and fester, and that scratches become very painful. They also believe that the steam from the sizing kettles carries with it unpleasant, if not harmful, fumes. The vegetable dyes which were formerly used have now been displaced completely by coal-tar dyes belonging chiefly to the azo acid group (Naphtol Blue Black and Naphtol Black B). It is highly improbable that harmful fumes could come from these dyes but there is one dyestuff, known to the trade as ursol, which is distinctly toxic and is used in some hat factories. This is para-phenylenediamine, a compound which has the toxic properties of the amido group of coal-tar derivatives and can be absorbed both through the skin and the respiratory tract, the absorp-

tion being hastened by heat and moisture. In color manufacture and in dyeing fur this compound is notoriously troublesome, causing a distressing trade eruption and, in susceptible individuals, attacks of bronchial asthma (6). Dermatitis has also occurred in persons wearing fur which had been colored with para-phenylenediamine (7).

The ordinary way of dyeing is to color the shaped and stiffened hat, and a chrome mordant is often required, potassium bichromate being generally used. This is admittedly a source of some trouble in the dyeing room. Chrome ulcers, slowly forming and painless, may develop on the ends of the fingers around the nails, on the nasal mucosa, and sometimes on the margins of the lips. There may also be a severe conjunctivitis. Both mordant and dye may be applied in open kettles, stirred by hand with long wooden rods, or in closed kettles, agitated by a stream of air, or in closed revolving cylinders which dip down into the dye at each revolution. According to the method used, conditions vary in the dyeing room and all extremes may be found in American factories from a Danbury plant in which only hand work is done over open tubs in steam and drip, to the model department at Stetson's, dry and airy, with its closed cylinders for hats, its closed kettles for fur, and no escape of steam anywhere. Second sizing by machine may follow dyeing.

Pouncing.—Pouncing is the name given to the smoothing process in finishing both soft and stiff hats which is done with the finest of emery paper by hand or by machine. The pouncing of soft hats is much more extensive and productive of much more dust than the pouncing of stiff hats. It comes before finishing and the men are called "pouncers," while pouncing stiff hats is a part of finishing and these men are known as "finishers." The soft hat finisher may do a little pouncing, but not much. An exhaust is always furnished to carry off the dust and, in the case of the pouncing machines, it is usually quite efficient. These machines are used on brims, the narrow brim being held between two sandpaper-covered surfaces. The man's hands are outside, consequently only a narrow opening is necessary, and the construction of shield and exhaust presents no difficult problem. But crown pouncing is almost always done by hand, and obviously it is much harder to prevent the escape of dust over this larger surface which cannot be so completely enclosed. The best device I have seen was in a New Jersey factory and may be seen in the Museum of Safety of the State Department of Labor in Jersey City. After pouncing, comes "rubbing off" of tips and brims with sandpaper, which is the same as pouncing, except that the block on which the hat rests moves back and forth instead of round and round.

To the uninitiated the amount of dust produced by pouncing seems insignificant, and yet enough of it is collected by the exhaust pipes to ship to fertilizing plants. All pouncing, as I have seen it done, is more or less safeguarded, but there is a wide variation in the efficiency of the different mechanisms provided. The process is performed twice, preliminary pouncing and final pouncing or, as it is sometimes called, "crown jigging." Preliminary pouncing may be done in the back shop by the hat makers; final pouncing always belongs to the front shop, and is done by hat finishers. If the suction apparatus is poorly designed or the draft feeble, fine dark dust can be seen

on the face of the pouncer, especially in the folds along the sides of the nose and on the chin. It is always men's work in the United States, in England, and in Czecho-Slovakia, but is done by women in Italy, where only machines are used, no hand pouncing. Hückel's factory also uses machines altogether.

In two factories, one in Danbury and one in Brooklyn, the draft to carry off the dust worked badly, the fine dust lay thickly over pipes, shields of exhausts, floor, and over the persons of the men, and it was significant that these men all chewed tobacco to help rid their mouths of the dust. In some shops, there is a great deal of brushing of the pounced hats, which increases the dust, and whirling belts keep the dust stirring. Two exceptionally dust-free pouncing rooms may be seen in the Mallory factory in Danbury and in Berg's in Orange.

Hat Finishing or "Front Shop"

Finishing. — Finishing consists in steaming and blocking to give the crown the final shape, drying, pressing by hand, or in an hydraulic press, singeing, oiling, and pouncing. Hot oil and vaseline are used to even up the color, alcohol or naphtha singeing to finish the surface. The highest temperature to which hats are subjected is in pressing, and it is probably in this department that mercury is volatilized to a greater extent than in any after sizing. Moreover, the finisher must bend down close to the hat while pressing, putting himself in just the position to inhale these fumes. Several authorities hold that the exposure to mercurialism is greater in finishing than in any other occupation of the trade. This work brings in other bad features, such as carbon monoxide from naked gas jets, naphtha fumes, and silicon dust. The heat for the irons is usually provided by gas and the grease is heated over gas. Electric irons are used in some New Jersey factories and at Knox's in Brooklyn, but gas-heated irons are much more common. Shaping also is done on gas-heated machines and all these processes may be carried on in one room, together with the pouncing. Unless these rooms are very large, the heat may be excessive—up to or even over 100° F.—and in one New York plant, Graham-Rogers and Vogt found four parts of carbon monoxide to 10,000 parts of air. The men employed here, classed together as finishers, say that these jobs, although highly desirable because of the good pay, are the most unhealthful of all.

Beaver Hats.—The making of beaver hats is not attended with risk of mercurialism. Beaver hats are made from non-carrotted fur on a wool felt body. The raw fur (hares' fur, for it felts poorly), which is to give the smooth, shining finish to the hat, is first formed in a machine very like an ordinary former but with a disk instead of a cone. This flat form is then "batted" on to the wool body, the man working at a plank like a sizer's and batting with a stiff brush dipped in boiling water which contains sulphuric acid. Wrapped in burlap, the body then goes through apron rolls through which live steam is driven into boiling acidulated water, the acid being stronger here. Jets of hot water raise the nap and a curry comb finishes it. The acid in the water eats away the wood of the tanks and they leak, the floors run with water and the steam is excessive, but there is no mercury used and no pouncing needed. The sulphuric acid is hard on the men's hands, and they protect them by smearing on tallow, but this is a

minor evil compared to those found in ordinary felt hat manufacture.

For convenience, a list of occupations in fur cutting and in hat making and hat finishing with the hazards in each occupation is given in Table 1.

TABLE 1.—SUMMARY OF PROCESSES IN FUR CUTTING, HAT MAKING, AND HAT FINISHING, WITH IMPORTANT HAZARDS OF EACH PROCESS

Process	Hazard
Fur Cutting	
Dampening raw skins.	Coarse hairs and dirt.
Opening up raw skins.	Coarse hairs and dirt.
Cleaning raw skins.	Coarse hairs and dirt.
Beaming and stretching.	Coarse hairs and dirt.
Plucking hairs or fur pulling.	Coarse hairs and dirt.
Shearing.	Coarse hairs and dirt.
Carrotting.	Fumes of nitric acid and of mercury.
Drying.	Mercury volatilized by heat. Direct contact with mercuric nitrate.
Storing carrotted skins.	Volatilized mercury, direct contact.
Brushing, cutting and sorting, weighing, and packing in bags.	Volatilized mercury, direct contact; fur dust.
Storing and removing from storage.	Volatilized mercury.
Blowing.	Dust; sometimes mercury.
Hat Making	
Removing bags from storage.	Volatilized mercury.
Weighing and mixing, blowing, weighing for former, coning, and hardening.	Volatilized mercury; fur dust; heat and moisture.
Starting, sizing, pulling out, blocking, whizzing.	Volatilized mercury; heat and moisture.
Preliminary pouncing.	Silicon dust and fine hairs; mercury.
Dyeing.	Heat and humidity; chrome mordants; coal-tar dyes.
Stiffening soft hats.	Heat and humidity, slight.
Shearing.	Hair dust.
Stiffening stiff hats.	Small quantity of methyl alcohol.
Hat Finishing	
Dry blocking, pressing in hydraulic machine, pressing with hot iron, singeing, final pouncing.	Carbon monoxide from gas; volatilized mercury; naphtha fumes; silicon dust and fine fur dust.

Women are found commonly in American factories handling the skins before carrotting, brushing carrotted skins, dampening them for storage, sorting the cut fur (rarely cutting), weighing and packing it in bags. They also weigh fur for the forming machines. All the final processes of stitching, lining, banding, and putting in leathers are carried on by the women, but these departments do not concern us. Boys are not often employed, although I have seen some apparently under 16 tending the drying stoves for carrotted skins. Young men in the late teens and early twenties are often found as sizers, especially in one large American factory, where some 200 are employed in this sort of work.

In European plants, women often do

cutting, inspecting, and pouncing, sometimes carrotting. As for young persons, the Belgian law of 1893 forbids the employment of anyone under 18 years in processes where nitrate of mercury is used, or in plucking or cutting if there is much dust. The French law of 1898 forbids the employment of any under 16 years in the fur cutting trade, and in 1899 the British prohibited the employment of children, who up to that time had apparently done what the British call locking, and we call sorting — *i.e.*, removing the inferior parts from the cut carrotted fur.

Industrial Insurance for Hatters and Fur Cutters

The three largest companies writing industrial insurance in the United States consider certain occupations in these trades of fur cutting and felt hat manufacture as distinctly above the average in danger to health, others as less dangerous, but unhealthful. Their selection of the undesirable ones, however, is not by any means the same. Thus, the John Hancock Mutual Life Insurance Company lists the whole industry, fur cutting and hat making, as doubtful, and the work of carrotting and of pouncing as extra hazardous. Fur cutters, hand carders, hand mixers, blowers, coners, wetters, hand starters, sizers, dryers, dyers, alcohol stiffeners, and foremen in these departments, are insured at rates above the ordinary.

The Metropolitan Life Insurance Company divides the employees into four classes, according to risk. In the ordinary class—that which has an expected mortality not over 20 per cent. in excess of the American Experience Table—are placed only the trimmers, welters and binders. Next, with an expected excess rate of 20 to 50 per cent., come all who are not listed in the other three classes. Special class jobs, with an expected excess rate of 50 to 100 per cent., include hand carders, blowers, hand mixers, hand starters, sizers and dyers. Special Class B includes those with an excess rate of 100 to 150 per cent.—fur cutters, carrotters, dryers, pouncers, and alcohol stiffeners.

The Prudential Life Insurance Company refuses to insure fur cutters, sizers, and makers. It accepts at increased rates: mixers, blowers, weighers, feeders, coners, wetters, hardeners, blockers, dryers, pouncers, singers, and trimmers; at ordinary rates: inspectors, finishers, shavers, curlers, flangers, stiffeners, and packers.

Summary

The trades of the hatters' furriers or fur cutters, of the hat makers and finishers have for centuries been looked upon as fraught with a high degree of danger to the workers. This impression prevails at the present day, especially in France, Belgium, and Russia.

The features of these trades which are regarded as dangerous are the use of mercuric nitrate to prepare the fur for felting, the handling of this fur in an atmosphere of heat and humidity which volatilizes the mercury and favors its absorption, the production of great quantities of fur dust and lesser quantities of silicon dust, together with minor evils, such as carbon monoxide from gas jets.

Fur cutting involves exposure to nitric acid fumes and volatilized mercury, and to excessive amounts of fur dust. Hat making is hot and wet, and the exposure to volatilized mercury is probably greater than in fur cutting. Hat finishing is dry, but the heat applied

in pressing volatilizes the mercury, and there are other bad features, such as silicon dust from emery paper, carbon monoxide from gas-heated irons and machines, and traces of methyl alcohol in the stiffening mixture.

The hygienic control of fur cutting shops in the United States is very imperfect, although there are a few brilliant exceptions to this statement. Hat factories have improved greatly of late, especially in New Jersey, but there are still many plants in which ventilation is poor, heat and humidity excessive, and the workers exposed to mercurial poisoning and to the inhalation of dangerous dust.

BIBLIOGRAPHY

1. Sanitary Standards for the Felt Hatting Industry. N. J. Dept. Labor, Trenton, 1915.
2. Heucke, K.: Die Gefahren in dem Gebrauche des Quecksilbers in der Industrie. Trans. XV Internat. Cong. Hyg. and Demog., Washington (1912), 1913, *3*, Part 2, 788.
3. Chaplet, A.: Le sécrétage des poils et les divers procédés chimiques de feutrage. Le Chimiste, Jan., 1912.
4. Monti, A.: Il mercurialismo cronico nei lavoranti in capelli di pelo. Il Ramazzini, 1909, *3*, 399 and 413.
5. Loewy, A., and von der Heide, R.: Ueber die Aufnahme des Methylalkohols durch die Atmung. Biochem. Ztschr., 1914, *65*, 230.
6. Von Criegern: Quoted by Kobert in Das Lehrbuch der Intoxikationen. Stuttgart, Ferdinand Enke, 1906, Vol. 2, p. 653.
7. Olson, G. M.: Dyed Fur (Paraphenylendiamin) Dermatitis, with Report of Five Cases. Jour. Am. Med. Assn., 1916, *66*, 864.

TIME AND MOTION STUDY*

E. Farmer, M.A.

Investigator to Industrial Fatigue Research Board

Part I: Review of Past Work

INTRODUCTION.—Time and motion study has become a phrase of common occurrence in industrial circles; yet little agreement exists as to its precise significance and little understanding as to how, and to what extent, such a study can be of use to industry. Some consider that a little attention to the time taken to perform an operation, and the method of doing it, should be sufficient to "at least treble output." Others form a much lower estimate of the probable value of these methods and consider it presumptuous for an outsider to come into a factory to teach others how to do their work. The truth as to the function of the study probably lies somewhere between these two extremes, but it is more likely to approximate toward the latter than the former. To talk of trebling output may be useful for commercial purposes, as being likely to attract the attention of those anxious to improve industrial methods, but if taken literally it is most misleading. Anyone who has carefully studied the subject in any industry must be impressed not so much with the ease of effecting improvements as with the practical difficulty involved in so doing.

We may define time and motion study in the following manner: *Time study* is the study of the time taken to perform each particular operation in an industrial task, and, from the data thus obtained, the endeavor to fix the proper time the task as a whole should take. *Motion study* is the study of the movements involved in a task with a view to eliminating such as are unnecessary and improving those that are necessary. It may be divided into *extensive motion study,* which is concerned with the arrangement of apparatus and the larger movements of the body involved in its use, and *intensive motion study,* which is concerned with the smaller movements of the hands and fingers. Time study and motion study are usually combined into one, called time and motion study.

In order to understand what may be expected from time and motion study, its origin and present development must be considered, and the exact aims that those engaged in it set before themselves; and also how far these aims are legitimate, and how far they can be attained by the present methods.

Taylor's System.—The object which Taylor set before himself was the standardization of labor, and, in order to arrive at the proper standard, he instituted a system of time study. His method was to divide work into its various elements and time them separately. The results were then summed, and a certain percentage added for unavoidable delays. Taylor's practice was to time first-class men who were induced to work as fast as possible by increased remuneration. As soon as the time study had been made, a workman was

*This article is based by the author on his Report No. 14 to the Industrial Fatigue Research Board, which contains further details and an extensive bibliography. Received for publication Feb. 8, 1922.

started on his new "task," which "required him to do between three and one-half and four times as much work in a day as had been done in the past on an average" (1).

The earnings of the men on the new system were, on an average, 60 per cent. greater than on the old system. The result was attained not so much by any improvement in the movements involved in doing the work as by fixing a certain standard time which had to be adhered to if the men were to earn the sum which they were obliged to earn in order to keep their places. Scientifically regulated rest pauses were also introduced, and these undoubtedly played an important part in the final result. Taylor advocated making the "task" as difficult as possible, so that only the best men could perform it. By this method he gradually eliminated all so-called second-class men.

Such a system may be commercially advantageous but it hardly goes to the root of the fundamental problems connected with the human element in industry. Much of Taylor's work is devoted to what he calls scientific management and a consideration of the best method of remuneration (2). The scope of the present memorandum does not extend to these aspects of Taylor's system; nevertheless, they form an essential part of his system, which rests more upon careful oversight and liberal payment than upon scientific principles connected with the human organism.

Considerable controversy has centered round Taylor's work. Some seem to regard all he did as almost beyond criticism. They point to his undoubted successes as sufficient indication of the essential soundness of his method, and regard all who criticize him as actuated by motives less worthy than those of Taylor. On the other hand, there are those who regard all that he did either with derision or direct hostility. They fasten their eyes on certain weak points in his system and refuse to consider those aspects which are of more lasting value.

To follow either of these extreme courses is unwise. When we think of Taylor's dealings with labor, either organized or unorganized, we must never cease to remember that he is dealing with labor conditions as they presented themselves in America, not with the conditions with which we are familiar in England. Certain points of his system may appear somewhat crude, but he was a pioneer in an unknown field of research, and we ought not to expect that his system could reach the standard of perfection, which those who come after him and who have the benefit of his experience may set themselves as the goal to be attained. Taylor's great and lasting contribution to the science of industry is the method which he adopted. He approached, in the spirit of scientific inquiry, problems which had been thought either not to exist or to be easily solved by common sense. He worked patiently for years to satisfy first himself, and then others, that by careful observation and accurate timing principles could be arrived at which governed the right employment of a worker's time and energy. Those who come after him and work upon the same problems, may criticize aspects of his system, and may disagree with certain of the ends which it has been made to serve, but nevertheless they owe him a great debt for indicating and developing a method, the possibilities of which are great.

Gilbreth's System.—Gilbreth set himself the same task as Taylor, namely, the standardizing of the human element

in industry; he, however, goes further than Taylor, for not only does he standardize the time for doing a task but he also standardizes the method. Taylor is mainly concerned with time study and rest pauses; Gilbreth is concerned with motion study as well (3).

Gilbreth's method is first to analyze an operation into its smallest constituent parts. These are then timed. With Taylor this would have been sufficient, for he would have taken the sum of these timings, plus the time allowed for unavoidable delays, and called that the standard time. Gilbreth, however, is not satisfied with this, but compares the different constituents of a given operation with the same constituents in a similar operation performed by other operatives. If the timings for different units of the operation vary in different workers, he selects the shortest timings from each operative, sees how the actual movements differ from those of other operatives who take longer to perform that unit of the task, and then sets a standard time composed of the sum of the shortest constituent factors in each operation, and a standard method of doing the work composed of the movements of those whose time is shortest. Thus, with two workers, whom we may call X and Y, he may find the timings of X for an operation consisting of four timeable units to be A, B, C, D, and the corresponding times of Y to be a, b, c, d. From these times he will select the shortest; let us suppose these to be A, b, C, d. He will examine the motions connected with each of these selected time units; A and C will be found among X's movements, b and d among Y's. These four movements coming from two different workers will then be combined into one series of movements which will be adopted as the standard method of doing the task, the standard time having already been arrived at by selecting the shortest time units from the two workers. This yields two parallel series which may be represented thus:

Shortest Time					Motion
A....	Motion	as	performed	by	X
b.....	"	"	"	"	Y
C....	"	"	"	"	X
d.....	"	"	"	"	Y

This method of procedure is interesting, and is a distinct advance on Taylor's method, which did not concern itself with the actual movements employed, provided that the task was performed in the standard time, the proper rest pauses were adhered to, and the final result was satisfactory to the overseer. Gilbreth sees that the method of doing work plays equally as important a part in the performance of any work as the time taken to do it. Gilbreth's methods would, however, have been more instructive if he had not introduced the disturbing factor that Taylor always introduced, namely, increased pay and various other methods of "encouraging the workers to put forth greater effort."

Further, it seems highly doubtful whether various movements, taken from different groups of movements, merely on account of their taking a shorter time to perform than similar movements in other groups, can be combined into an independent group which would yield results as satisfactory as either of the original groups. The method of performing a given task is similar to the so-called "style" of a cricketer or golfer, who certainly would not build his style on a composite mixture of other people's styles. It is far more satisfactory to study one style and become perfect in that, than to study many styles which may yield only the

result of being imperfect in all. We cannot, however, pass final judgment on the method because it has never been tried by itself unaccompanied by special inducements to increased effort; but the results which Gilbreth has obtained do not prove that there is *a* best method of doing any operation. There are, undoubtedly, good methods and bad methods; the good may be encouraged and the bad discouraged, but the actual method finally adopted by the worker must be the one which he finds most convenient, that is, the one best suited to his physical and psychological make-up.

Criticism of Taylor's and Gilbreth's Methods.—Both Taylor and Gilbreth set before themselves the definite task of standardizing the human element in industry. They wanted to make industry more efficient by reducing the cost of production. Some people, when they attempt to reduce the cost of production, think primarily of lowering the wages paid to labor, but Gilbreth and Taylor made no such mistake. They both realized that to reduce the cost of production by such a method is, in ordinary circumstances, short-sighted and fails in its real object.

They approached the subject from a more scientific standpoint, and attempted not to reduce the wages of labor but to increase them, provided that such an increase is accompanied by an increase in output. They did not leave it at this, but, by their methods of time and motion study, they sought to ascertain how and in what degree real improvement was possible.

The method adopted by them was one that paid considerable attention to the welfare of the worker. Taylor was careful to see that sufficient rest was introduced into the day's work, and Gilbreth has gone further and paid attention to such things as comfortable seating and bench accommodation. Nevertheless, in spite of these considerations their systems have met with a great deal of opposition on the part of labor, a fact that gave Taylor great concern. Hoxie (4) in his report on "Scientific Management and Labor" and also the committee appointed by the House of Representatives in its report show clearly that in factories working under the Taylor system there is evidence that the workers think they are required to work at a speed which, in the long run, is detrimental to their health. Still, the evidence taken from workers by the committee appointed by the House of Representatives is to the effect that no real objection is felt to those parts of the Taylor system which deal with systemization and standardization, but that strong objection is felt to the methods of stimulation.

This objection to methods of stimulation seems to go to the root of the whole matter, both from the workers' point of view and also from the point of view of those whose approach to the question is one purely of scientific interest. The latter realize that there is a physiological and psychological background to the whole of human effort, and they want to discover whether the methods adopted in time and motion study really go to the root of the matter and indicate more economical ways of utilizing human effort. Great improvements in efficiency have been effected by the introduction of new ways of performing certain industrial operations, but whenever these improvements have taken place, there have been two changes, one in method, and one in the system of remuneration, and we are at least entitled to inquire which is the predominating factor.

Workers can certainly be spurred to

greater effort by methods of remuneration calculated to penalize the slow workers and reward the quick worker, but such results are of more interest to those who are studying methods of remuneration than to those whose only concern is the fatigue of the worker. Taylor was not studying either; he was primarily concerned with the problem of output, and set himself the task of increasing the production of the various firms in which he worked. He is quite frank on the matter. He says (1, p. 143): "All employees should bear in mind that each shop exists, first, last and all the time, for the purpose of paying dividends to its owners." This is not the place to offer any criticism of such a statement, but anyone holding that view and, at the same time, devoting himself to the problem of production. will clearly use different methods from those employed by persons concerned primarily with the fatigue of the worker.

The above criticism must not be taken to imply an objection to any particular system of payment, or to change in the method of payment; but such systems or changes should be unaccompanied by any change of method if they are to provide data bearing on the problem of increased effort. Similarly, any change of method which is to yield reliable data bearing on the same problem must be unaccompanied by any change in the system of payment.

Both Gilbreth and Taylor make their systems depend primarily upon speed. Taylor always timed the quickest worker, and the standard which he set for any task was based on the results thus obtained. He certainly added a percentage of time to cover unavoidable delays, and also instituted regular rest pauses, but what he always sought was speed. In no less a degree does Gilbreth make speed his ideal. He regards the quickest movement as the best, and even goes so far as to say that in teaching a new movement speed must be insisted on from the very first. He regards speed as more important than accuracy of movement or quality of work. His reason for adopting this point of view is that the path a movement follows is different when the movement is done quickly from when it is done slowly. This is, in the main, true, but even so, whether speed should be insisted on from the beginning may be regarded as doubtful.

Further, we may doubt whether speed is the best criterion for judging a movement. From Gilbreth's point of view the quickest movement is the best, and so long as speed is the object to be attained this must necessarily be so. Nevertheless, the quickest movement may not be the easiest and the best for the worker to accustom himself to. It may make too great a strain on the nervous system to be advantageously employed by all workers. As has already been pointed out, these quick movements are selected from various workers; possibly they may in some way be closely connected with the physical and mental make-up of the worker in question, and their transplantation as isolated motions into the movement system of other workers may be unwise.

Standardization.—The standardization of the human element in industry is the object which both Taylor and Gilbreth put before them. The former sought mainly to standardize the time to be taken in performing a task; the latter went further and standardized the method also. Standardization of all human effort would, without doubt, be a great convenience for employers, especially if that standard was a con-

siderably higher one than they were wont to expect, but in setting this standard the greatest caution must be exercised.

In the first place, we must consider whether, from the workers' point of view, the fixing of a standard that they are required to reach is advisable. It may become a constant source of irritation to them to feel that they must reach a certain standard every hour, or every day, as the case may be. On certain days when they are suffering from slight indisposition not sufficient to keep them away from work, they may wisely do less work than they might be able to do if they exerted all their effort. On other days when they are feeling extremely energetic, they may be able to surpass the standard, and if left to their own devices they might do so. The thought that they were only expected to keep up to the standard might debar them from putting forth all their energy, lest the standard should again be raised and made more difficult to attain on days when they were not feeling particularly energetic.

Beside these personal factors that might affect the workers' ability to reach the standard, there are those influences which all workers are affected by, though in varying degrees. Among these we must count temperature and weather conditions, and the physical factors that periodically affect women.

With regard to the standardizing of motions, it is doubtful if a set of movements, however good, can necessarily be regarded as the best for every person concerned. Personal differences must be allowed for and the possibility admitted of the worker's discovering a method better suited to his requirements than the prescribed one. In the majority of cases the standard method may prove the best, but in no case should it be forced upon a worker. Every worker should be taught the standard method and then allowed to follow his own devices, provided the results are satisfactory.

New Point of View in Undertaking Time and Motion Study.—If time and motion study is to be systematically adopted in industry, then those who are engaged in it must endeavor to avoid certain errors that have been made in some of the applications to which it has been put. The object for which the work is undertaken must be different, and the type of men employed in the study must likewise be different.

The literature dealing with time and motion study shows that it has been left far too much to those whose main object is the increase of output in some particular industrial concern. Hence the tendency at times has been to overlook the fundamental principles lying at the base of the study, and to concentrate attention on the immediate results to be obtained in the particular factory in which the person carrying on the study is interested. If, however, real advance is to be made along the lines which Taylor and Gilbreth have indicated, the matter must be treated from a broader viewpoint. Improvements in particular factories are not sufficient, however useful they may be, but an endeavor must be made to discover the general principles that govern human effort in industry. So long as the matter is left entirely in the hands of those whose main object is increased production there will be a tendency for the worker to feel, rightly or wrongly, that he is in some way being exploited. If, on the other hand, he realizes that the study is being carried on by those whose only interest is lessened fatigue, he will learn to regard the matter in an entirely different light.

Certain preliminary investigations have to be made before motion study proper can be undertaken, and the first of these is the investigation of unproductive labor. In almost all industrial operations that have not been regulated according to a well-thought-out plan, a considerable amount of time is wasted by the skilled worker in purely unproductive labor. It may take many forms. The skilled worker may be required to fetch the materials on which he is to work, or to remove them when he has finished. He may be required to prepare the tools which he is to use, or to perform some operation subsidiary to the main one. Such unproductive labor may not, in itself, be a bad thing, since it may provide a rest for muscles that are continually being used in the main operation; in so far as this is the case and such rest cannot be conveniently provided otherwise, it is undesirable to have this work done by a less skilled worker. Whether such interruptions in the work are advantageous or not will depend largely on the nature of the work and the amount of energy put forth in performing the tasks that act as interruptions to the main occupation, and this can only be determined by actual experiment. Besides the actual labor that a worker may be required to do on jobs subsidiary to his main purpose, he may be kept waiting from time to time on account of the method of supply. Whether this enforced rest is beneficial or not is also a matter for experiment, and must be governed by such factors as regularity and duration of the pauses.

Motion Study Proper.—Motion study, according to the definition already given, seeks to eliminate unnecessary movements and to improve necessary ones. This may be taken as a general definition, which will include various methods of improvement. What is meant by improvement must be understood before judgment is passed on the desirability of motion study.

If speed is the object sought, the value of any movement must be judged by its speed. There may, however, be another standard by which movements can be judged, namely, that of the ease with which the worker can perform the movement in question. Those who take this view will dismiss the speed factor entirely from their minds. They will endeavor only to devise some method of doing the task in question, which will be more in accord with physiological and psychological laws, and which will utilize the natural aptitudes of the worker in a more efficient way. Those working on this principle will not seek to discover how quickly a worker can perform a task, but will endeavor to arrange that the task may be done in such a way as to interfere in the least possible degree with the worker's rhythm. The effort of the worker, and not the task, will become the center of attention.

If this principle is adopted, the question arises as to how we are to know whether improvement has taken place by the introduction of a new set of movements. The method usually adopted has been to accompany the introduction of a new system of movements with a carefully devised method of payment calculated to stimulate increased effort and to penalize any falling away from the standard that has been set. Under this system increased output is regarded as an indication that the system of movements introduced causes less fatigue to the worker than the movements that were superseded. This may or may not be the case.

At present there is no reliable measure of fatigue that can be applied un-

der factory conditions, and until such a measure is discovered we must content ourselves by judging the success of a new system of movements in the following way.

The essential features of the new method should be, first, that it is more in accordance with physiological and psychological laws, so that the body and mind are used in the most economic way by avoiding all possible strain. Secondly, the new method should meet with the approval of workers who have given it a fair trial, and should have the result of making them feel less tired and more satisfied with their work. If these requirements are fulfilled, then the result may be regarded as satisfactory.

An increased output may or may not result. This will depend on how much improvement has been effected. If it is sufficiently large to allow the body to do more work, then greater output, if the same hours are worked, will be the natural result. If shorter hours of work are adopted, then the result may take the form of doing the same amount of work that was previously done in longer hours. If the improvement is not so great, the only result will be that the worker is less tired after the day's work than he was before. The inability to make so large an improvement as to affect output under the conditions laid down, must in no way be attributed to the experimenter or the worker. The nature of the work may be such that an appreciable improvement affecting output is impossible, either because the work is so fatiguing that the body soon reaches its limit under any system, or because the sphere in which motion study can be applied is too small.

In all cases that have come to the writer's notice, where the principle suggested has been the basis of a new set of movements, increase of output and increase of earnings have actually taken place, though in no case was any effort made to get the workers to increase their output.

Rhythm.—In most industrial processes there is a set of movements which is strictly necessary for the performance of the work; there is another set which is made necessary by the bad arrangement of materials or the inexperience of the workers; and there is a third which can only be accounted for by assuming that it represents the rhythm to which the worker has become used. The first set of movements cannot be done away with as long as the work remains essentially the same, but it can be altered by intensive motion study. The second set of movements can be entirely eliminated or altered by what has been described as extensive motion study, but the third set is the most difficult to deal with, and also the most necessary to deal with if the fatigue of the worker is to be the real concern of the investigator.

These three sets of movements are not really separate, but together form a group of movements which has become traditional in the performance of any industrial process. Some difficulty may be experienced in determining to which set any particular movement belongs, but if the matter is to be properly taken in hand the attempt has, at least, to be made. When unnecessary movements have been eliminated by extensive motion study and necessary movements improved by intensive motion study, the experimenter must consider how far the remaining movements, due to the sense of rhythm in the worker, are necessary, and how far they can be modified and improved.

The ideal is to make the necessary

movements so rhythmic and graceful that no extra movements are needed as an appeal to the worker's sense of rhythm. Generally, workers who have had long experience at a particular type of work develop a great number of unnecessary rhythmic movements which may be difficult to give up. Probably attempts should seldom, if ever, be made to get workers who have become accustomed for many years to one set of movements to relinquish them in favor of another set. The movements have become semi-automatic and great discomfort is caused in any attempt to break a formed habit. Beginners are different. If they are taught a graceful and rhythmic set of movements from the beginning they will form habits of work which, when once established, will be difficult to give up; but such habits, if based on scientific time and motion study, will render work so much more easy than under the old system that presumably there will be no necessity for them to be given up.

If the improved set of motions is of really rhythmic character, there will be little tendency to superimpose other rhythmic motions on it. A superimposed rhythmic movement is one which is not actually necessary to the performance of the task, but which is introduced by the worker, possibly in order to synchronize with some physiological rhythm whether of muscular contraction, heart beat or breathing. But whatever their cause, these movements should not, unless they are having markedly bad results, be objected to.

The sense of rhythm should form the basis of any scientific system of movements, but naturally no rules can be laid down with regard to it. The object which an experimenter should place before him is to devise a set of movements that will do the work properly and, at the same time, be able to set up rhythmic motor habits in the worker. One movement should follow on naturally from the one preceding it, and the terminal phase of the preceding movement should naturally suggest the initial phase of the next.

A large field of research lies open along these lines. At present, little is known about rhythm in industrial processes, although it must play a large part. However much a method of doing work may be improved, there are always variations in the effect which it has on different individuals. The average of output may be raised, but the variation about that average remains the same. This variation may be due to many causes. Rhythm and motor control probably play a large part in it, and it may also be in some way affected by varying types of fatigability. Research into these problems would be of great service to those who are interested in the subject of time and motion study.

Part II: Examples of Motion Study

An Experiment in Sweet Dipping.— The process of "dipping" consists of putting a "center" (an almond, walnut, Brazil nut, or caramel) in a basin of melted sugar with the left hand, and covering it with the sugar by working it with a fork held in the right hand, and then placing the finished sweet on a tray. The path usually followed by the worker's hand when dipping was found to be such as Figure 1 may illustrate. (See page 165.)

This diagram does not, of course, represent the exact line followed. No human movement would ever be so exact, besides which no account has been taken of certain small movements made necessary in order that the sweet may

be of the proper size. The exact path followed by this movement may be seen in Figure 2, the lettering in which corresponds to the lettering in Figure 1. The stroke AB is not given in Figure 2. Its commencement can be detected at about the same place as is afterwards covered by C. In Figure 3 its commencement can be more easily seen.

The right hand holding the fork goes from A to B and takes up a portion of the thick liquid and pulls it over the "center" at X. When the hand reaches C it goes forward toward the left side of the bowl with the end of the fork under the center. The center is then picked up at D and deposited in the tray. This would appear to be the best way of doing the operation, because the hand is always travelling in approximately straight lines. The defect of this method is that the hand stops at B and goes in the opposite direction and also at C and goes again in the opposite direction. The necessity of having to stop the arm twice and change the direction causes unnecessary strain to the arm muscles.

After some personal experience on the part of the experimenter in the process of dipping, he decided to recommend a method in which the hand moved in curves instead of in straight lines. The new method is diagrammatically represented in Figure 4.

The hand, after depositing the finished sweet, leaves A and reaches B on the surface of the boiled sugar in the middle of an inward and downward curve with the hand in its strongest position for doing work. The momentum gained by the movement A—B is thus utilized for the most tiring part of the work instead of being entirely wasted by checking the movement in order to change its direction, as in the old method. This curve sweeps the sugar over the center and, going under it in the second part of the curve, comes up again at C. The sweet is then deposited on a tray. A circle in the same direction is made there, also, in order to finish off the sweet. In this method the hand is never brought to a sudden standstill but continues in an even circular movement, all change of direction being effected by curves and not by stopping the hand. Moreover, it has the advantage that the fork strikes the boiled sugar (the part of the process offering the greatest resistance to the hand) with a downward and inward stroke and with the full momentum gained by travelling from A to B. In the old system this part of the process was done by a short backward movement just after the hand had stopped and changed its direction. The diagram of this motion should be compared with Figure 3, in which the curve B—C can be clearly seen. Figures 1 and 4 represent the movement as seen by the worker; Figures 2 and 3 represent the movement as done by the worker and seen by the observer standing in front of the worker.

The best workers in the department were then examined to see if any of them worked in the method suggested. The three whose output was greatest were found, at times, to adopt a method similar to, though not quite identical with, the one suggested. Workers who had been accustomed for years to another method of work could not be induced to adopt the new method. An endeavor was therefore made to get the younger members of the department to adopt it, and for this purpose a class was instituted. The result, after a short period of training, was an average increase of 27.1 per cent., but even this increase did not fully represent the benefits to be gained by the new method.

The instructress who had charge of this class was not a very proficient teacher, and the young girls, seeing older girls around them working in a different way and, of course, turning out more than the younger girls were able to, showed a tendency to drop the method which they had been taught, and to adopt the one which they found going on all around them, and, apparently, producing better results.

For this reason attention was concentrated on a new room that was to be started. A more proficient instructress was found, a new-sized table and trays were employed, and arrangements were made whereby the workers were enabled either to sit or stand while at work. This new room was lighter and better ventilated than the old one had been. After three months' work in the new room the workers were, on an average, producing 88 per cent. more than workers of the same standing who were using the old method in the original room. This increase meant that girls of 14 and 15 years were earning a sum equivalent to that earned by girls of 18 in the old room, showing that the correspondence between age and output in the old room was not entirely due to the superior strength of the older girls, but that difficulty in forming an easy motor habit at least had something to do with it. The new system of movements was far more natural than the old one and, therefore, presumably easier to learn.

An Experiment in Bottling Sweets.—The process of putting sweets into small glass jars is one that entails a considerable number of operations. The experimenter noticed that the workers tended to do nearly all the work with the same hand. They would pick up the jar from the right hand side with the right hand, work on it with both hands, and put it down on the left hand side with the right hand. Or they might pick up with the left hand from the right side and put down on the left side with the left hand, and every other possible combination of right and left hand was to be found. He thought that if the work could be more equitably apportioned between the two hands, and some system devised where both hands worked simultaneously instead of one working while the other rested, a more satisfactory way of doing the work might be found.

A distinction must here be made between ambidexterity and bimanufiability. By the former is meant the power of being able to do an operation equally well with either hand; by the latter, the power of doing one thing with the one hand while doing something else with the other. Persons who shave themselves with either hand are ambidexterous; persons who can put down an object with one hand while taking up another object with the other are bimanuficient. Ambidexterity is not brought into play in the process of bottling here described, but bimanufiability is.

A system of movement was devised which depended on the latter quality being utilized, and elaborate diagrams were made of the movements for each process, but the workers could not be made to understand what was required of them. A method of doing the work was, therefore, devised by which the whole process, instead of being done by one worker, was done by a team of workers, each worker doing one particular operation. To facilitate matters, a moving belt was placed on the bench along which the jars traveled to be thrown off close to the worker who was to do the next process.

In order to avoid having any worker

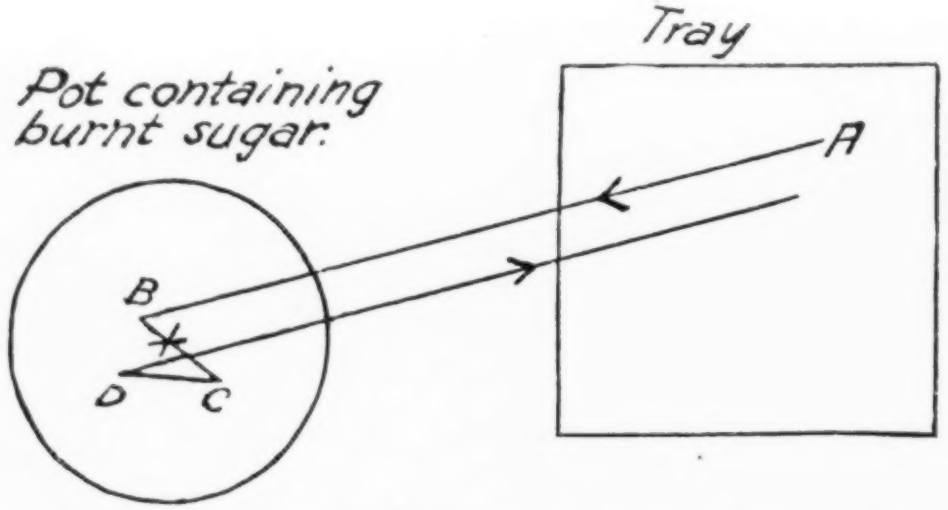

FIG. 1.—Diagram of old method of sweet dipping.

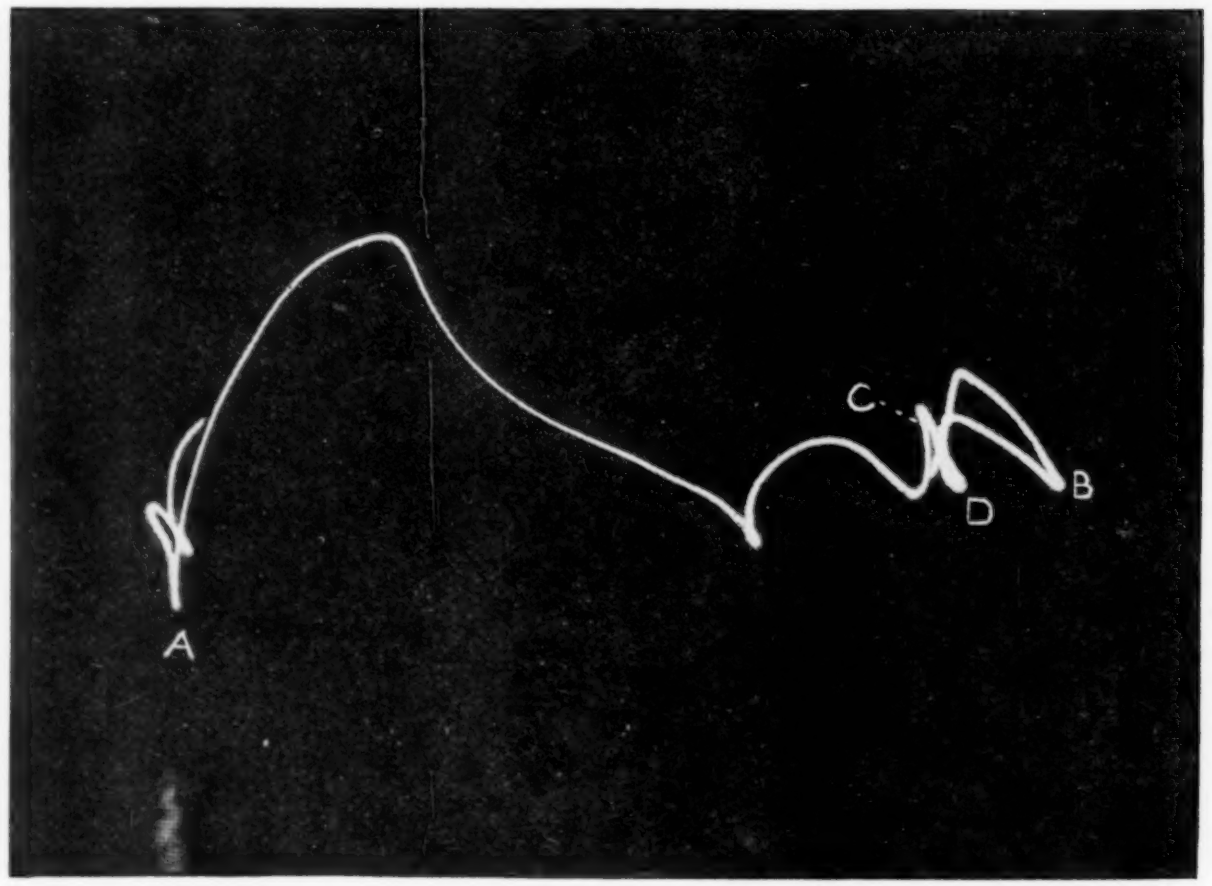

FIG. 2.—Usual method of sweet dipping.

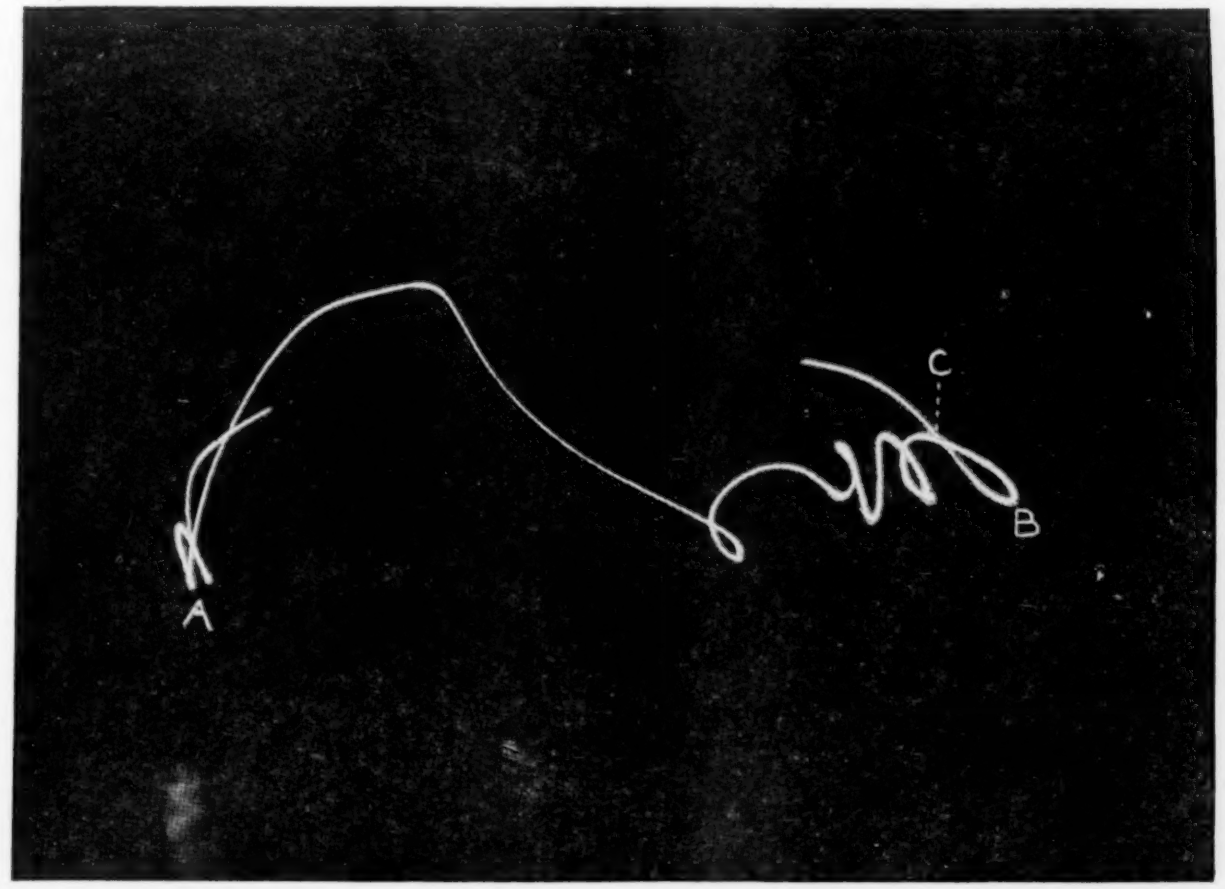

FIG. 3.—New method of sweet dipping.

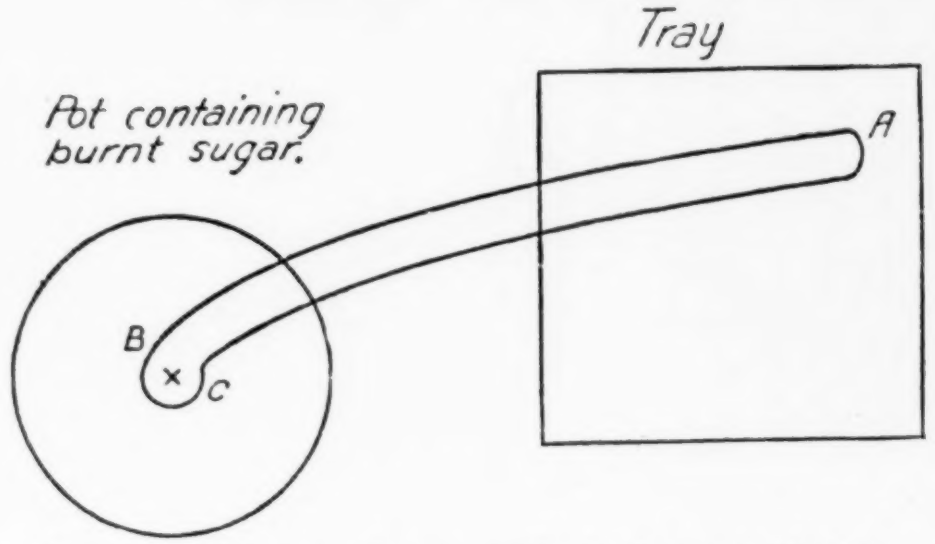

FIG. 4.—Diagram of new method of sweet dipping.

perform one process for too long a time, no girl was required to screw lids on to the jars for more than half an hour. This operation was the most tiring in the process. The relief given to the "screwer on" provided an opportunity for a change for each worker every half hour, which was better than any arbitrary arrangement that it might have been necessary to make, if all the processes had been of equal difficulty.

The new system, after working for some time, resulted in the workers' average output and earnings being about 50 per cent. greater than when the previous system was in vogue. Further than that, so much floor space was saved by the new method that the room will accommodate 90 per cent. more workers than was previously possible.

The interesting feature of this experiment is that the method of work adopted provides that the jar to be worked upon shall always arrive at the right hand side to be picked up by the right hand, and that the jar that is finished is always put down on the left hand side; this process is facilitated by the belt. The result is that without any instruction the workers have learned to pick up one jar while they put down another, in fact have learned in this respect to become bimanuficient.

An Experiment in Covering Chocolates.—In covering chocolates, the worker drops the center into the chocolate with the left hand and covers it with a **fork held in the right** hand.

Almost every worker in the chocolate dipping department was found to possess a different method of work. Some were able to perform the operation with a comparatively small number of movements, and others employed a greater number of movements. The workers differed in the size of the movements which they employed, some making extended movements though few in number, and others making the same number of movements though less extended in nature. This can be illustrated by reference to Figures 5 and 6.

The investigator hoped that he would be able to reduce the number of movements employed by getting the workers to adopt the rhythmic curved movement which was employed in sugar dipping, but he realized that no definite rule could be laid down as to the exact number of movements necessary on account of the technical difficulties connected with the thickness and temperature of the chocolate. He therefore decided to suggest a method and to leave it to each worker to determine how many movements she would take to do the work.

The workers found the new method so easy that in a few months their piece rate earnings were equal to the earnings of girls of several years' standing. When they had reached that standard they were moved into the room with the other workers. Many of the older workers became most interested in the new method and began to pay attention to the number of movements employed. The forewoman was of the opinion that the new method had had a most beneficial effect upon the whole department, and she was sure that the dippers as a whole were employing fewer movements.

An Experiment in Chocolate Packing.—There are various ways of arranging for a supply of chocolates to be packed, but the most usual is either to arrange the chocolates on trays, one above the other, immediately in front of the worker, or to have them in boxes spread out before the worker in two horizontal planes. The system of pack-

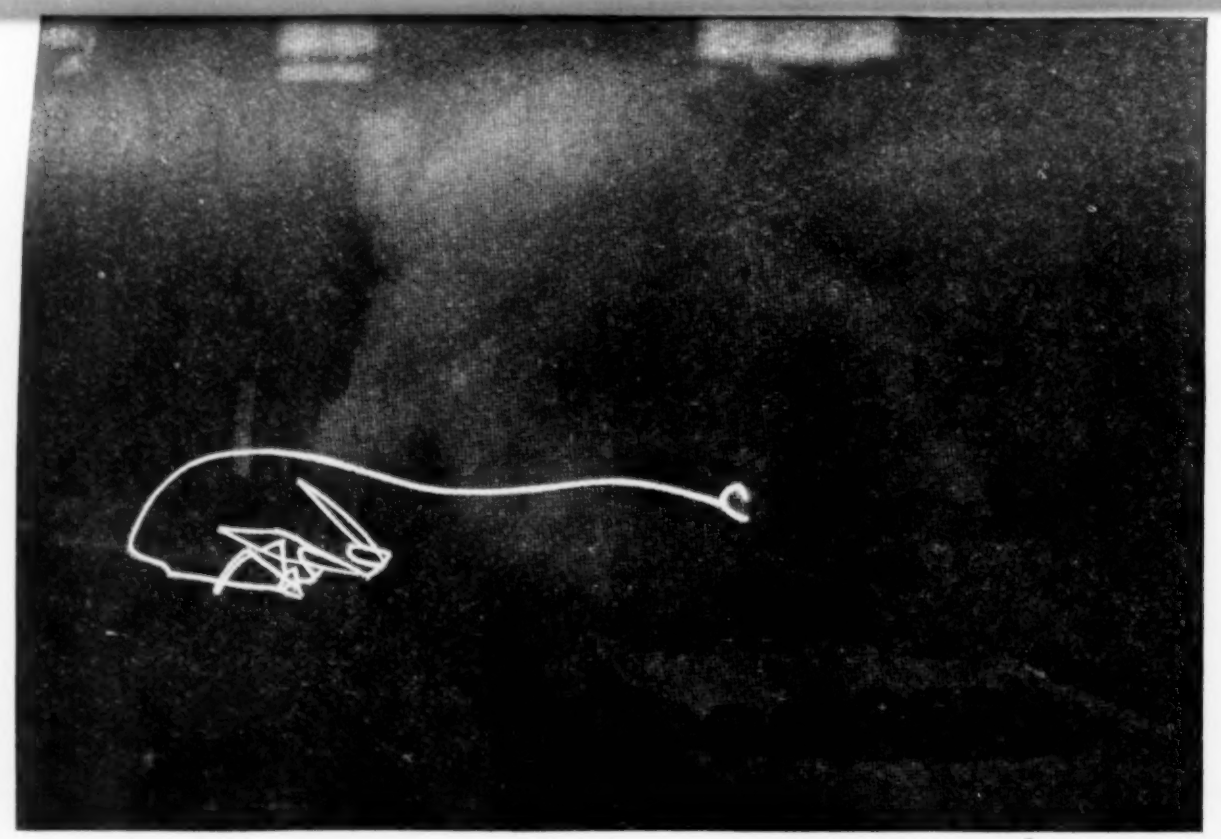

FIG. 5.—Best worker in chocolate packing department.

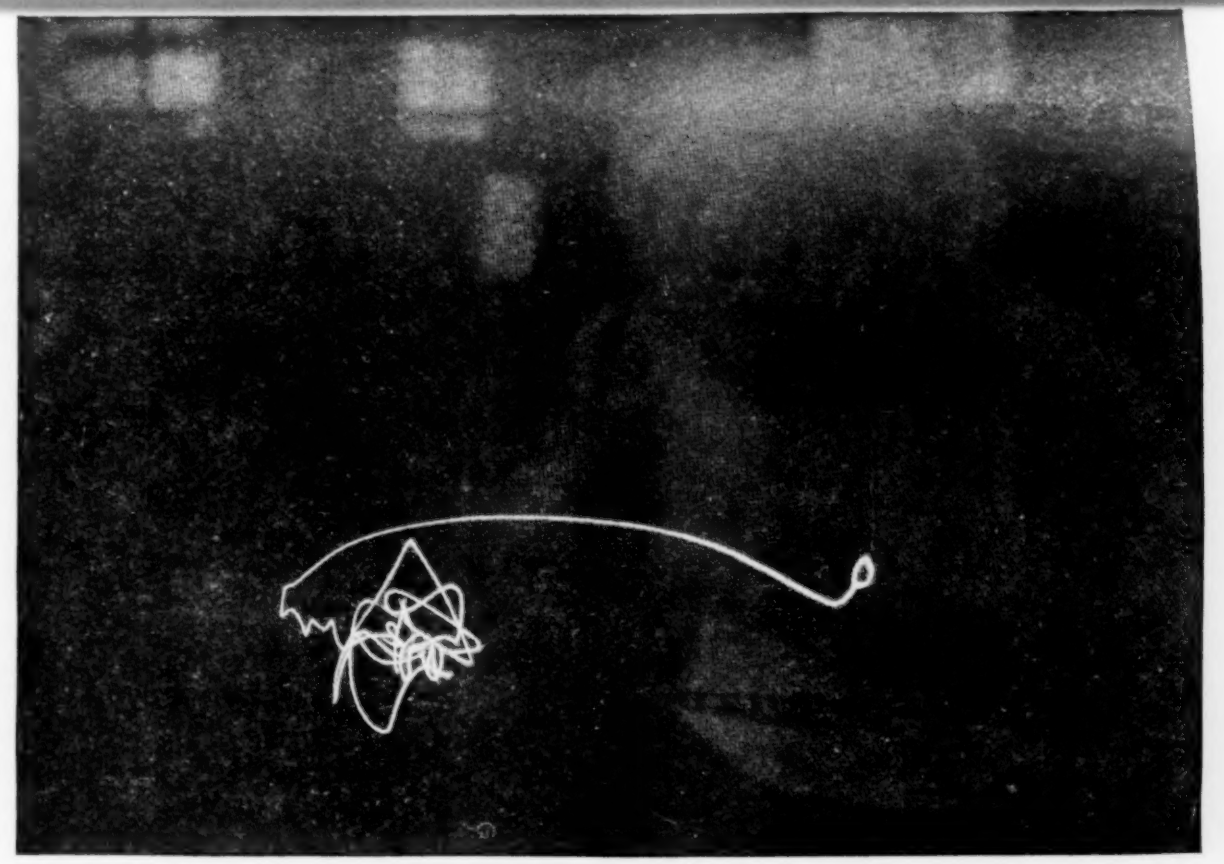

FIG. 6.—Worker of many years' experience making many unnecessary movements.

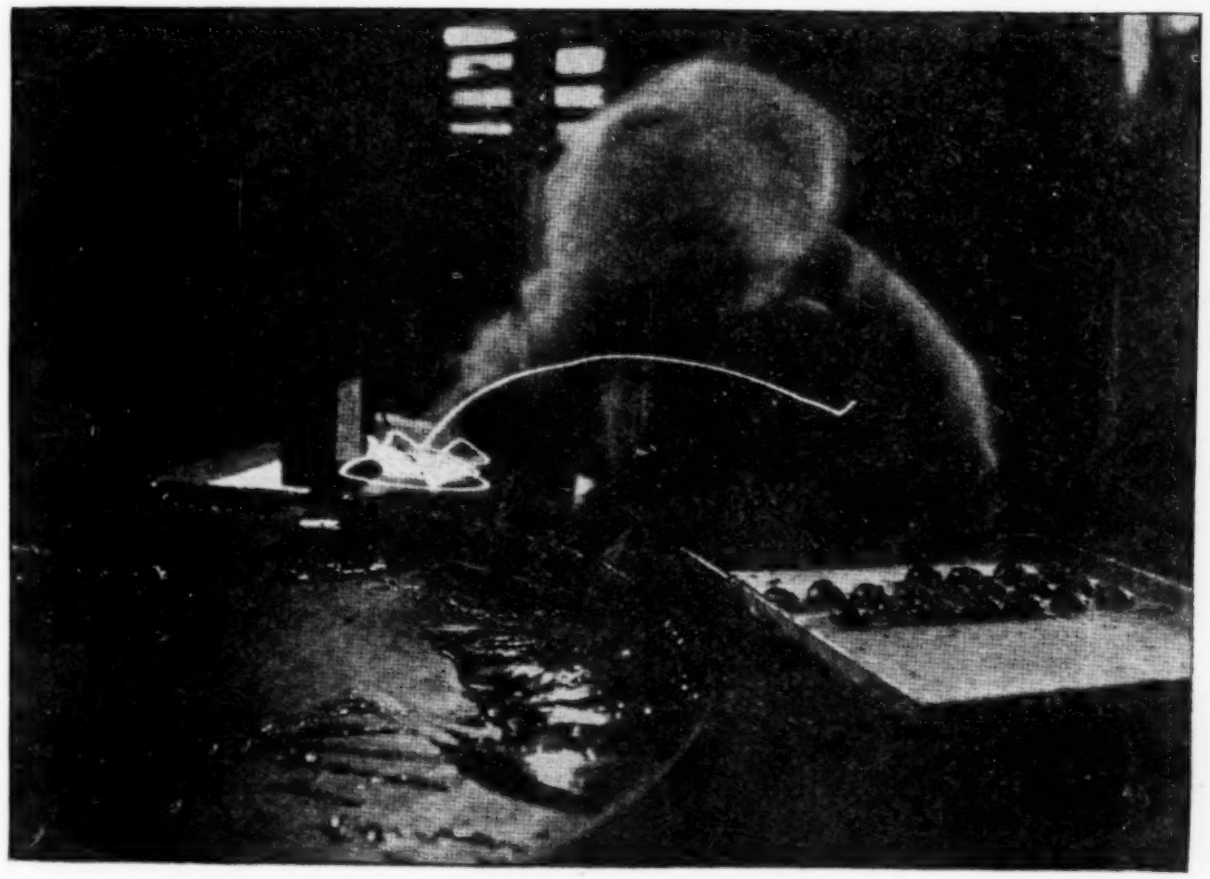

FIG. 7.—One of the pupils after six months' experience.

ing in vogue in the particular factory in which the experiment was carried out was of the latter type.

The only way to insure easy rhythmic movement on the part of the worker was to design patterns which made it possible and which at the same time were attractive to the eye. This was done, with the result that the new patterns necessitated that chocolates be taken from the boxes in something like the following order:

Bottom Layer	Top Layer
1, 2, 3, 4,	11, 12, 1, 2,
5, 5, 5, 5,	3, 3, 3, 3,
6, 7, 8, 9,	4, 5, 6, 7,
10, 10, 10, 10,	8, 8, 8, 8, etc.

This is only an example, and an infinite number of patterns are possible which still allow the worker to move in an ordered way. The worker's hand still has to move from the center of the bench, where the box which she is packing is situated, to the circumference where the boxes from which she is taking chocolates are situated; but instead of having to make a separate decision each time a chocolate is required as to which box to find it in, her movements can now be made in a semi-automatic fashion, simple movement associations being formed which directly correspond with the visual association of the required pattern.

A new bench was designed which enabled the worker to sit while at work, and the boxes from which she was packing were arranged in a semi-circle instead of in a straight line in front of her. The sides of the semi-circle worked on hinges and could thus be easily adjusted by the worker to the position in which she found it most comfortable to work. The new method of packing resulted in an increased output of 38 per cent.

In all these experiments no stimulus of any kind was given to the workers to increase their output. The principle in each case was to devise what was believed to be an easier way of doing the work and then to leave the matter in the workers' hands.

Summary

Time and motion study is of great industrial importance. It was introduced by Taylor and followed up by Gilbreth with the direct object of increasing output; the former timed the quickest workers, while the latter, by timing units of movements, determined a shortest possible time; both these pioneers urged on workers to attain the pace fixed. Workers object that both these methods which aim only at speed result in unhealthy drive.

A new point of view is now proposed which concentrates attention on ease of movement and not on speed of production, on the effort of the work and not on the task. The object is, by making necessary movements rhythmic and graceful, and by eliminating unnecessary movements, to minimize fatigue and produce pleasure in work. Increased output is not the objective, and may or may not result. It is significant, however, that in every case that has come under the writer's notice, where this new principle has been employed increase of output has in fact resulted.

Practical applications of this new point of view at a process of sweet dipping resulted in an increase of output of 88 per cent.; at bottling sweets, in an increase of 50 per cent.; at covering chocolates, in greatly shortening the time required for acquiring proficiency; and at chocolate packing, in an increase of 38 per cent. No stimulus was used in these experiments to induce the operatives to work faster.

BIBLIOGRAPHY

1. Taylor, F. W.: Shop Management. Harper and Brothers, New York, 1911.
2. Incentives to Work. Interim Report, Health of Munition Workers' Committee (Cd. 8511). H. M. Stationey Office, London, 1917, p. 69.
3. Gilbreth, F. B., and Gilbreth, L. M.: Applied Motion Study. Sturges and Walton, New York, 1917.
4. Hoxie, R. F.: Scientific Management and Labor. D. Appleton and Company, New York, 1918.

TUBERCULOSIS AS IT AFFECT S THE INDUSTRIAL WORKER*

FRANK A. CRAIG, M.D.

From the Phipps Institute of the University of Pennsylvania, Philadelphia

THE relationship between tuberculosis and the industrial worker is so complicated and involved, and presents so many phases of interest to the industrial physician, that it would be impossible to do more than refer briefly to certain of the more important phases of the subject. There is no disease which is so important from the standpoint of the industrial physician, as it appears in so many varied forms and may so completely disable the workman, frequently after a prolonged period of partial disability with the loss of a considerable amount of time and efficiency. The onset is usually so insidious that the disease becomes well advanced before its true nature is recognized.

During recent years great stress has been laid upon the importance of childhood infection with tuberculosis, and the frequency of adult infection has been questioned, but the studies upon which this view is based are of such a character that it would seem inadvisable to neglect any of the precautions which have hitherto been employed to prevent the dissemination of the tubercle bacilli among adults. In industry the detection of the disease is of the utmost importance to the employer, the employee affected, and his fellow-workers.

The relationship between tuberculosis and industry constitutes one of the most important problems bearing upon the prevention of this disease, the solution of which unfortunately presents many difficulties. It is almost impossible to determine in any individual case how important a part has been played by occupation, and to what extent home environment and mode of living have been responsible for the development of the disease. A weak point in most of the studies of tuberculosis in industrial bodies lies in the fact that the home conditions of the workers have been ignored. The disease is extremely prevalent among the poor industrial workers—that large group which is usually exposed to crowded, poor living conditions, poor food, dissipation, and similar factors which we know may be responsible for the development of the disease and may favor its spread.

There can be no question that working under unfavorable conditions results in an increase of the disease and that improvement of the general hygienic conditions of the plant is followed by a reduction in its frequency. Industry, then, bears the same relation to tuberculosis that the home environment bears to it; it is just as essential that the working conditions should be favorable as that the home conditions should be. In studying tuberculosis in any given industry, one must not only consider the special trade processes involved, but also the general conditions as to light, ventilation, etc. There are certain trade processes and occupations, especially those in which irritative types of inorganic dust constitute a hazard, which have such a high mortality rate from

*Read before the Section on Industrial Medicine and Surgery of the College of Physicians, Philadelphia, Feb. 24, 1922. Received for publication March 27, 1922.

tuberculosis that they have always been regarded as definite predisposing factors.

The effects of industry have been summarized by Dr. Hayhurst (1) as follows: (1) deaths from industrial diseases are rare; (2) specific occupational diseases, such as, for instance, those due to poisons, are fairly common; (3) nonspecific occupational diseases, represented by chronic infections and degenerative processes, are very common; while (4) health complaints in which the occupation enters as a chief factor are almost universal. He further states, "It is startling when we realize that such an innocent occupation as that of the telephone girl is associated with a tuberculosis rate of 43 per cent. of all deaths among this class of workers, and that the stenographer suffers a rate of 39 per cent. from the same disease."

Another phase of the tuberculosis problem of considerable practical importance, especially from the standpoint of the industrial plant, is the relationship between pulmonary tuberculosis and trauma. Evidence regarding a sufficient number of cases has been established in which tuberculosis has followed traumatism—in individuals known to have been free of all evidence of the disease prior to the injury—to warrant one in accepting trauma as a possible cause for the development of the disease. The physical examination of applicants for employment and the frequent re-examination of employees are the only means of protection which a plant possesses against being unjustly held responsible for tuberculosis in persons who, when injured, claim that the traumatism is responsible for the disease.

When one studies the frequency with which tuberculosis is encountered in industrial bodies, one encounters difficulty in securing data so formulated that a definite comparison of one plant with another can be made. Some statistics refer to males, some to females, and others to both sexes. In some instances where both sexes are included, the proportion of males and females, with the corresponding rates, is not given. Often no mention whatever is made of the sex of the workers. Similarly, no distinction is made between white and colored workers. Very few statistics give the average age of the workers and practically none are arranged according to age group. Rarely is mention made of the exact occupation of the individuals affected. Occasionally the number of examinations is given, but generally no reference is made to the total number of workers employed, the reason for the examination, the method of examination, or the grounds upon which the diagnosis was based, etc. Some physicians employ the term "serious lung defect," and fail to state the nature of the defect; some include suspected tuberculosis and definite tuberculosis under one heading; others include them under separate headings. It is not surprising, in view of this lack of uniformity, that the tuberculosis incidence rates in Table 1, which I have collected from various sources, show such an exceedingly wide variation, running all the way from 0.02 per cent. to 6 per cent. The definite tuberculosis cases in which the complete figures are given show an average of 1.494 per cent.

The great variation between the findings of the different authors in various industries cannot be accepted as being indicative of the influence of the industry itself upon the prevalence of the disease, as there are too many other factors which must also be taken into consideration—such as age, sex, color, methods employed, and the individual opinion of the examining physician as

to what physical signs and symptoms are to be considered as indicating the presence of the disease, and as to what care was exercised in making the examination. This personal equation of the examining physician is probably one of the most important factors involved. While the incidence rates given in this table are by no means constant, they are sufficient to indicate that the disease is so generally prevalent as to warrant our employing every possible means to prevent it.

Viewing the problem from a slightly different angle, it is interesting to see how many days per employee are lost annually through tuberculosis. In his excellent article on industrial absenteeism, Dr. Quinby (18) states that in the industrial plant of which he is medical director pulmonary tuberculosis was responsible for the loss of 0.246 days per employee during the year 1920. Excluding acute infections of the upper respiratory tract, tuberculosis had the second highest rate of any disease or group of diseases. Diseases of the stomach had a higher rate (0.297), and rheumatism had a slightly lower rate (0.235). This gives one a clear appreciation of the importance of tuberculosis from the industrial standpoint.

Fortunately, we have at our command a method of detecting tuberculosis among industrial workers, namely, by means of entrance examinations combined with periodic health examinations. If carefully conducted, this procedure will undoubtedly help materially to reduce the number of cases within a relatively short period of time, provided the hygienic condition of the plant is good. It must be borne in mind, however, that by examinations I mean complete examinations for all defects and diseases, for it is neither practical, economical, nor expedient to conduct an investigation of this kind for the detection of one disease alone. As a matter of fact, every defect or disease detected and corrected, and every step taken to improve the health and well-being of the individual is a step toward the prevention of tuberculosis.

The entrance examination has been fairly generally employed and is in operation in a large number of plants because it is a procedure which more readily appeals to the employer, promising a definite, tangible return by eliminating the seriously disabled and diseased workmen, and also serving as a control on the type of work which may be performed by workmen with a moderate disability, preventing them from engaging in an occupation which would aggravate their defects. The results to be obtained by periodic health examinations are not so obvious to the employer, and consequently it is difficult to convince him of the value of a health program in which both entrance examinations and periodic health examinations are included.

While the entrance examination may serve to keep out of the plant seriously diseased individuals and may help to place men at work for which they are physically fitted, it is concerned only with the new employee — usually the least valuable to the plant—and does not include the valuable workmen who have been in the employ of the plant for some time. Any attempt to keep these older employees under observation by examining them when sick is of relatively little value to the plant; they should be examined periodically before they become actually ill, when the first manifestations are present, and at a time when a change of occupation, perhaps, or treatment while at work may be sufficient to prevent illness.

Tuberculosis is a disease which, like

TABLE 1.—TUBERCULOSIS RATES IN INDUSTRIAL STUDIES COLLECTED FROM VARIOUS SOURCES

Author	Industry	Title of Defect	No. of Cases	Incidence Rate	No. Examined	Applicants	Employees	Male	Female
				%					
Auel (2)	electric mfg. co.	serious lung defect	17	0.09	18,390		x	x	
	" " "	" " "	44	0.14	29,805		x	x	
	" " "	" " "	90	0.50	17,858		x	x	
	" " "	" " "	2	0.05	3,628		x		x
	" " "	" " "	4	0.07	5,583		x		x
	" " "	" " "	1	0.03	2,944		x		x
Buzby (3)	leather works and cannery	unquestionable tuberculosis	—	0.80	1,500	x	x	x	x
Lowman (4)	steel company	lung disease	35	0.28	12,302	x	x	x	
	" "	" "	59	2.42	2,430	x	x	x	
Kellogg (5)	department store	active tuberculosis	19	3.80	500				
		inactive tuberculosis	8	1.60	(2,000 employees; 85% females)		x	x	x
	" "	active tuberculosis	6	3.00					
		inactive tuberculosis	2	1.00	200	x		x	x
Kellogg (6)	" "	tuberculosis	42	3.47	1,210		x	x	x
Clark (7)	grinding company	lung rejections	5	0.19	2,618	x		x	
Cutler (8)	" "	pulmonary tuberculosis	10	0.50	2,000	x		x	
Scheffel (9)	not stated; medium but hazardous	tuberculosis	1	0.33	300	x		x	
Britton (10)	International Harvester Co.	"	—	0.88	about 20,000		x	x	x
			—	0.54	" "		x	x	x
Schereschewsky (11)	garment workers	pulmonary tuberculosis	65	3.11 } 2.49	{ 2,086		x	x	
	garment workers	the same	9	0.9 }	{ 1,000		x		x
Price (12)	bakers	" "	—	2.40	800				
	tailors	" "	—	1.60	800				
	tobacco workers	" "	—	1.30	600				
	furriers	" "	—	6.00	83				
Fisk (13)	insurance policy holders	possible tuberculosis of lungs	—	1.40	——		x	x	x
	commercial employees	the same	—	0.90	——		x	x	x
Mock (14)	clerks, 35% light skilled, 20% heavy mfg. and laboring, 45%	active tuberculosis	—	1.70	112,000		x	58%	42%
	miscellaneous, reports of ten surgeons	" "	—	1.40	——		x		
	steelworkers—U.S.P.H.S.	" "	—	0.92	936		x		
Robinson and Wilson (15)	miscellaneous	pulmonary tuberculosis	—	1.07 } 1.10	14,049		x	x	
Craig				1.89 }	5,883		x		x
	policemen and firemen	the same	103	1.80	5,706		x	x	
War Department (16)	drafted men	pulmonary and suspected tuberculosis	—	2.202	——			x	
	drafted men in Pennsylvania	the same	—	1.947	——			x	
Doty (17)	telegraph co.	tuberculosis	36	0.49	7,201	x		68%	32%

many others, usually develops insidiously, the patient frequently not considering himself ill until the disease is well developed or even advanced. This fact was strikingly illustrated in the examination of the policemen and firemen of the city of Philadelphia, recently conducted by the Phipps Institute of the University of Pennsylvania, in which nearly two-thirds (64 per cent.) of the cases of tuberculosis discovered had previously been entirely unsuspected, even by the affected individuals themselves.

In order to prevent the infection of other workmen and to secure a retention of the working capacity of the individual affected with tuberculosis, with the loss of only a relatively short period of time, the disease must be discovered early. There is no method for this early detection of disease which is at all comparable with periodic health examinations.

For the foregoing reasons I would like to make a special appeal for the installation of this method of study in every industrial establishment. While serious objection will, no doubt, be raised to such an elaborate and time consuming procedure, I believe that the difficulties are not insuperable and that the results obtained would more than compensate for the cost involved. It is impossible to estimate how great would be the influence upon the public health of a widespread employment of periodic examinations. A recent study of periodic health examinations by one of the large insurance companies has clearly demonstrated their economic value to such an organization, and I can see no reason why they would not be of equal financial value to an industrial plant. There can be no question that, from the standpoint of tuberculosis at least, the general employment of periodic physical examinations would constitute one of the most effective measures that could be devised for the advancement of preventive medicine.

To be of value it is essential that the examinations be made with thoroughness, care, and precision; otherwise the early cases of tuberculosis will be overlooked. There is no disease which varies more in its clinical manifestations than does tuberculosis; in some cases the general symptoms predominate, and in others the pulmonary signs are most marked. The latter type of case is more easily recognized by the examining physician than the former, which is frequently confused with some other disease. While the early recognition of the disease is not always easy, in the majority of cases a careful examination will reveal its presence. It is a mistake to view the early diagnosis of pulmonary tuberculosis as a very difficult procedure requiring expert training, employment of the roentgen rays and similar costly methods. More early cases pass unrecognized, through carelessness or neglect to examine, than are undetected on account of lack of training. There are, to be sure, a certain number of cases which tax one's diagnostic ability very severely, but they constitute only a relatively small proportion of the total number.

The cases which present the most difficulty are those in which there are symptoms or general signs suggesting the presence of tuberculosis, but in which the physical signs in the chest are indefinite or obscure; or, on the other hand, those in which there is definite evidence of pulmonary disease, suggesting tuberculosis, in which the sputum remains negative for tubercle bacilli. In both of these types of cases it may be found necessary for the in-

dustrial physician to seek the assistance of some one who has had considerable experience in diseases of the chest and who has access to laboratory facilities which will aid him in establishing a diagnosis.

The method to be employed in carrying out entrance examinations is so well known that it is unnecessary to refer to it at this time. The periodic health examinations constitute more of a problem, the method of procedure varying with the size of the plant, the number of workmen that can be spared from work at one time, the medical equipment of the plant, etc. The frequency with which they should be carried out is also a difficult question to decide, as I have so far been unable to discover any accurate studies which would throw any light on this question. In very hazardous occupations it is customary to make examinations at frequent intervals, even every month, but in the average plant they are made at intervals of one, two or three years, according to the judgment of the medical officer.

The industrial plant with a medical staff of its own should experience no difficulty in making periodic health examinations, provided they were taken into consideration at the time when the medical staff was organized, or provided the personnel is increased to permit their being made. They may be made continuously throughout the year, each employee reporting for re-examination about one year from the time of employment and again each succeeding year, or it may be less disturbing to conduct an intensive study of all employees within a short period of time, preferably during the slack season. For the latter method it may be necessary to have the examinations conducted by some outside agency in order to avoid interfering with the routine medical service of the plant.

The plant which has no regular medical officer or only a part-time physician will find it almost impossible to have periodic health examinations made without the help of some outside agency unless the number of employees is so small that the part-time physician can make the examinations along with his routine work.

The need for some organized agency, which could assist in the work of conducting health surveys and could serve as a group diagnostic center for obscure cases, so impressed the Henry Phipps Institute that it organized such a team of examiners and established a diagnostic clinic for the use of industrial plants in and about Philadelphia, the object being to provide a service which would cover all disabilities and not merely tuberculosis. The recent period of business depression seriously interfered with the health survey work but the diagnostic clinic is now in operation and is handling cases from several large industrial establishments.

Summary

In the foregoing paper I have attempted to give an outline of the tuberculosis problem as it affects the industrial worker. An unusual opportunity is here offered for the introduction of preventive measures, such as, for example, periodic health examinations, the results of which would be felt in the industries themselves and, if sufficiently widespread, would have a beneficial effect upon the health of the public. The review of the subject has also made evident the need for a more carefully developed and more uniform method of statistical report.

BIBLIOGRAPHY

1. Hayhurst, E. R.: The Relation of Industry to Medicine. Ohio State Med. Jour., 1916, *12*, 20.
2. Auel, C. B.: The Unexpected Trend in Accident Prevention. Management Engin., 1921, *1*, 35.
3. Buzby, B. F.: Defects Affecting Fifteen Hundred Men. Nation's Health, 1921, *3*, 612.
4. Lowman, J. B.: Value of Physical Examination as a Factor in the Prevention of Industrial Injury. Penn. Med. Jour., 1916, *20*, 48.
5. Kellogg, F. S.: Medical Supervision of Employees. Penn. Med. Jour., 1920, *23*, 667.
6. Kellogg, F. S.: The Rehabilitation of Employees: An Experience with 1,210 Cases. Jour. Indust. Hyg., 1921-1922, *3*, 276.
7. Clark, W. I.: Medical Supervision of Factory Employees. Jour. Am. Med. Assn., 1917, *68*, 5.
8. Cutler, R. W.: Physical Examination of Factory Employees: Two Thousand Consecutive Cases and the Defects Found. Boston Med. and Surg. Jour., 1917, *177*, 627.
9. Scheffel, C.: Physical Examination of Applicants for Industrial Positions; with Results of Three Hundred Examinations. Med. Rec., 1919, *96*, 925.
10. Britton, J. A.: The Relation of Medical Examinations of Employes to the Hygiene of the Working-Place and the Efficiency of the Working Force. Nat. Assn. for Study and Prevention of Tuberculosis, Tr. Tenth Annual Meeting, 1914, p. 47.
11. Schereschewsky, J. W.: Studies in Vocational Diseases. I. The Health of Garment Workers. U. S. Pub. Health Ser., Pub. Health Bull. No. 71, 1915, p. 17.
12. Price, G. M.: Occupational Diseases and the Physical Examination of Workers. Tr. Fifteenth Internat. Congress of Hyg. and Demography (1912), 1913, *3*, 844.
13. Fisk, E. L.: Some Results of Periodic Health Examinations. Pop. Sc. Month., 1915, *86*, 324.
14. Mock, H. E.: Industrial Medicine and Surgery. Philadelphia and London, W. B. Saunders Company, 1920, p. 365.
15. Robinson, D. E., and Wilson, J. G.: Tuberculosis among Industrial Workers. Report of an Investigation Made in Cincinnati with Special Reference to Predisposing Causes. U. S. Pub. Health Ser., Pub. Health Bull. No. 73, 1916, p. 11.
16. Defects Found in Drafted Men. U. S. War Dept., 1920.
17. Doty, A. H.: The Value of Examination of Applicants for Industrial Employment. Med. Rec., 1916, *89*, 952.
18. Quinby, R. S.: A Study of Industrial Absenteeism. Nation's Health, 1921, *3*, 572.

CERTAIN ASPECTS OF THE PROBLEM OF ZINC TOXICITY*

PHILIP DRINKER, B.S., CH.E.

From the Laboratories of Physiology, Harvard Medical School

INTRODUCTION

THE toxicity, physiological action, and distribution of zinc and its compounds are of importance chiefly as the oxide, their most inert example. Finely powdered metallic zinc, as such, is not absorbed through the skin by handling and is encountered industrially only in the form of blue powder. There appears no evidence in the literature that ill effects from blue powder occur in the industries where it is used the most: namely, in sherardizing, in the cyanide process, and in the manufacture of certain dyes. Whether in the form of powder or spelter it is very generally, and with entire justice, classed as of no importance from the toxicological standpoint.

Isolated cases of skin lesions and burns from zinc chloride have been reported from time to time. Their nature and treatment are well understood and their occurrence can be ascribed to carelessness. Compounds such as the sulphate have no importance from the standpoint of industrial hygiene.

Zinc oxide is daily receiving greater industrial application. It is used extensively in the compounding of rubber goods, in the manufacture of paint, linoleum, oil cloth, glass and porcelain, in the preparation of zinc salts, especially the chloride, and in other less important industries.

BRASS FOUNDERS' AGUE

In several industries, of which brass manufacture is the best example, zinc is heated to a temperature at which it exerts a high vapor tension. The burning of this vapor then produces zinc oxide in a state of extreme particle fineness. The inhalation of the oxide in this condition has been held to cause the malady known under a variety of names, of which *brass founders' ague,* or more simply *the ague,* will be used hereafter.

Symptomatology.—More than seventy years ago descriptions of the ague appeared, and these have been accurately reaffirmed so often that they need but a brief word in addition. A few hours after exposure to air containing the freshly formed oxide, a dryness in the throat is noticed which gives rise to a tendency to cough. General lassitude, an oppression in the chest sometimes resulting in difficult breathing, and occasionally vomiting, are other early symptoms. After leaving the casting room, which is usually warmer than the outdoor air, chills are induced, ultimately developing into *shakes* with an attendant rise in temperature which passes off in a few hours with copious sweating. This series of events creates a desire for warm drinks, of which milk seems to be in the greatest favor. With the passing of the fever the patient sleeps soundly and arises the next day feeling slightly weak but not incapacitated for work. While the ague rarely causes absence from the foundries, it has been repeatedly reported that on Mondays and on days following holidays workmen are more susceptible—a fact which indicates that an immunity

*Received for publication June 7, 1922.

is developed by habituation to the fumes. Alcoholism is claimed by some as a factor enhancing individual susceptibility.

Treatment and Prevention.—No specific treatment has been shown to be universally effective. It is claimed that warm milk induces precipitation of zinc albuminates and thus rids the system of the cause of the ague, but this theory has by no means been proved. Although warm drinks may be of help, warm water would probably be about as effective.

It has been demonstrated repeatedly that good ventilation will prevent the ague. The problem should, therefore, be placed in the domain of preventive medicine, and the occurrence of trouble ascribed to ignorance or, more generally, to gross carelessness.

Thermophysics and Chemistry of Zinc Oxide Formation

In the medical literature on the ague there are many erroneous and unfortunate statements on the physical chemistry and metallurgy of zinc. These errors are so widespread and have appeared in so many articles and textbooks that it seems pertinent to this subject to discuss the more important factors governing the formation of zinc oxide. Furthermore, these factors are essential to an adequate understanding of the ague. Except in the splendid monograph by Gillett on "Brass-Furnace Practice in the United States" (1) —and this was written from the standpoints of metallurgy and metallography —no accurate accounts of the ague on the basis of the thermophysics and chemistry of zinc oxide have appeared in the literature. Gillett's work should have done much to dispel the errors which have appeared, but it has apparently not received the recognition which it has deserved. Although our knowledge has progressed since the publication of this monograph, there are so many valuable data compiled in it that free recourse has been had to its pages in the preparation of this article.

Heat of Formation of Zinc Oxide.—Pure zinc melts at 419.4° C. (2) and, under normal pressure of 760 mm., boils at between 920° and 930° C. (3), the exact boiling point still being subject to dispute. For convenience the range 920° to 930° will be used in this paper, and it is sufficiently accurate for the purposes intended.

To produce 1 gram-molecule of zinc oxide (81 gm.)[1] it is necessary to burn 65 gm. of zinc with 16 gm. of oxygen. If this is done calorimetrically in the laboratory, one starts and ends with all three substances at 0°C. or makes the calculations as if such were the case. This reaction results in the liberation of 84,800 calories. To have the reaction actually take place, however, either the zinc must be in a fine state of division, as is the case with blue powder, or else sufficient heat must be supplied. Once the reaction is started, it will proceed to the quantitative formation of zinc oxide, provided that there is ample oxygen present.

If zinc is boiled in an open crucible, of graphite for example, with walls sufficiently high so that the complete conversion of zinc vapor into the oxide does not take place until the vapor has risen above the mass of boiling liquid, sufficient heat to start the reaction is already present in the zinc vapor. Unless this heat, 36,345 calories (4), is added to the 84,800 calories representing the formation of zinc oxide with the reaction starting and ending at 0°C., a value below the correct one is obtained. The oxida-

[1] Decimals may be ignored.

tion of boiling zinc is, therefore, exothermic to the extent of 121,145 calories per gram-molecule of zinc oxide formed.

The fact that zinc vapor is quantitatively converted into the oxide, if the vaporization takes place in an oxidizing atmosphere, is the basis of the processes by which thousands of tons of oxide are produced today. If the reaction were not quantitative and other zinc compounds or metallic zinc formed, they would unfailingly appear in the chemically pure or even the commercial grades of oxide. The fact that such is not the case is well shown by the following analyses, kindly furnished by the New Jersey Zinc Company.[2]

ANALYSIS NO. 29078: SAMPLE OF ZINC OXIDE "SPECIAL"

Analysis on material as received:

	Per Cent.
Insol.	0.026
H_2O	0.244
CO_2	0.038
Total S as SO_3	0.240
Cl	0.036
PbO	0.096
CdO	0.023
Bi_2O_3	Absent
CuO	"
Fe_2O_3	0.017
MnO	0.006
As_2O_3	0.053
ZnO (difference)	99.199
Sb_2O_3	0.022

ANALYSIS NO. 40339: SAMPLE OF ZINC OXIDE "SELECTED"

Analysis on material as received:

	Per Cent.
Insol.	0.023
H_2O at 110°C	0.230
CO_2	0.036
Total S as SO_3	0.224
Cl	0.067
PbO	0.094
CdO	0.019
Bi_2O_3	Under 0.001
CuO	" 0.001
Fe_2O_3	0.022
MnO	0.013
As_2O_3	0.036
ZnO (difference)	99.203
Sb_2O_3	0.033

In the commercial manufacture of zinc oxide two processes (5, p. 281), the French or indirect and the Wetherill or direct, are in general use. In the former, zinc vapor is burned as it issues from a battery of small retorts in which metallic zinc is boiled. In the Wetherill process, as applied by the New Jersey Zinc Company (6) at Palmerton, Pa., the source of zinc is oxidized ore in which the zinc may be considered present as the oxide to the extent of 18 to 22 per cent. Advantage is taken of the heat remaining in the furnace from the previous charge which, with forced draft, serves to ignite a layer of anthracite coal. On this is placed the oxidized ore intimately mixed with fine anthracite coal. The temperature used commercially for the reduction of zinc oxide is in the neighborhood of 1200° to 1300° C. (5, p. 37), so that the reduced zinc appears in the vapor and not in the metal state. Thus, the zinc oxide is first reduced to zinc vapor and then re-oxidized. The oxidation takes place above the charge bed and is complete when the fume enters the suction pipes leading to the bag filters, where the oxide is collected and packed for shipment.

Heat of Formation of Certain Other Metallic Oxides.—The burning of zinc quantitatively to its oxide has numerous analogies among other metals and particularly those entering into brass, the most widely used zinc alloy. To be comparable in their tendency to form oxides, their several heats of formation should be compared on the basis of equal weights of oxygen, of which 16 gm. gives a convenient unit. Calculated in this

[2] See also Hofman (5, p. 282).

manner for a few of the metals, we have the following (4):

Oxide	Per Gram-Molecule *Calories*	Per 16 Gm. of Oxygen *Calories*
Mg,O	143,400	143,400
Al_2,O_3	392,600	130,500
Zn,O	84,800	84,800
Cd,O	66,300	66,300
Sb_2,O_3	166,900	55,633
Pb,O	50,800	50,800
Cu_2,O	43,800	43,800
Cu,O	37,700	37,700
Pb,O_2	63,400	31,700

The second reaction on this list is the basis of the Thermit process, in which the heat liberated by the burning of aluminium is sufficient to reduce iron oxide and furnish molten iron for welding. Of the zinc, cadmium, lead, and copper group, it will be seen that zinc heads the list by a considerable margin. Once the reaction is started it will, therefore, proceed with greater violence than in the cases of the other three metals.

Manufacture of Commercial Zinc or Spelter.—Owing to the facts that the temperature of reduction of zinc oxide is well above its boiling point and that the zinc vapor formed by such reduction oxidizes with extreme ease, zinc smelting cannot be carried out in the manner in which iron is reduced in the blast furnace.[3] The processes used today for the manufacture of metallic zinc are fundamentally the same everywhere. Zinc ore in the form of oxide, roasted sulphide, or carbonate, is mixed with approximately equal parts of a reducing agent such as anthracite coal, and placed in a small clay retort or still to which is attached a clay condenser. The still is heated by gas flame, and when the mass reaches the reducing temperature of zinc oxide, zinc vapor is evolved in the retort, passes to the condenser and is there condensed to the liquid. Oxidation always occurs to a slight extent in spite of the strongly reducing conditions, and some oxide is formed even in the condensers and is used in subsequent charges. Carbon monoxide results from the reduction of zinc oxide with carbon, and burns with the small amount of uncondensed zinc as both gases issue from the condenser.

The trifling quantity of oxide which forms in the condensers tends to condense the metallic zinc to the form of very fine droplets coated with a film of oxide. In the commercial production of blue powder the condenser is kept below the melting temperature of zinc. The blue powder formed is extremely fine and burns with great ease — with so much ease, in fact, that it is stored in a dry atmosphere to avoid fire hazard (5, p. 35).

Vapor Tension of Zinc and Certain Other Metals

If the vapor tensions of the metals are plotted with tensions as abscissae and absolute temperatures as ordinates, the curves are asymptotic with the x and y axes. This makes the interpolation of points at low pressures or high temperatures subject to great inaccuracy. If the logarithms of pressure are used as abscissae and inverse absolute temperatures as ordinates, the curves become approximately straight lines so that the accuracy of boiling-point determinations under various pressures can be checked by observing whether these points fall along the calculated straight lines. In this manner vapor-tension data of the metals have been collated and presented by Johnston (7). Curves from his data for copper, tin, lead, zinc, and cadmium are reproduced in Figure

[3] Attempts have been made to carry out such reductions at high pressures but with results of no commercial interest.

1. Considering the vapor tension of zinc under any temperature as an index of its tendency to volatilize, and, if in the air, to oxidize, this tendency can be computed from the curve. At the temperature of galvanizing (approximately 475° C.) zinc exerts a tension of 0.16 mm. (computed from the curve), while under boiling conditions its tension is 760 mm. Consequently the formation of oxide tends to proceed about 4,750 times

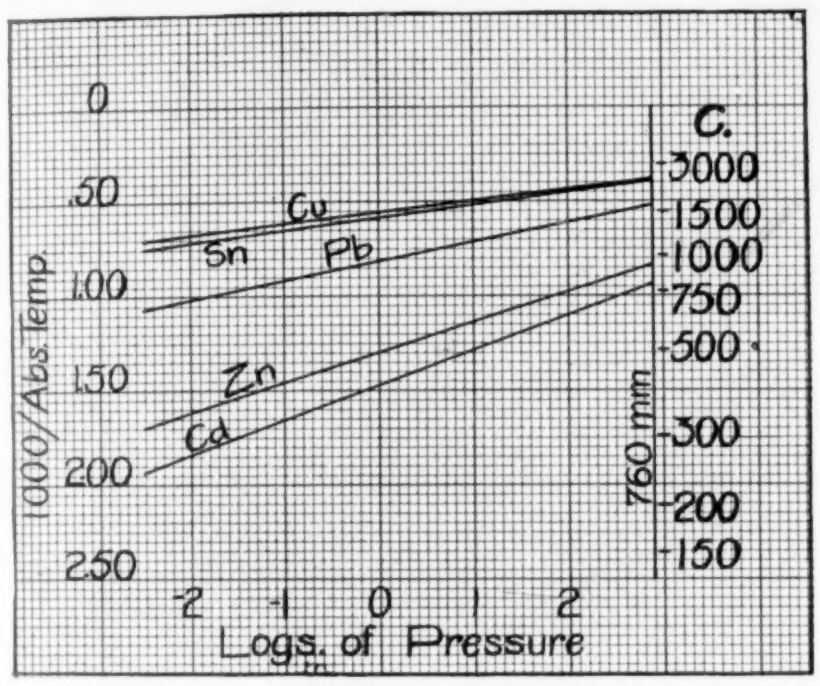

FIG. 1.—The vapor pressure of certain metals (7).

as rapidly when zinc is boiled as in ordinary galvanizing. Assuming that zinc oxide, formed by oxidation of vaporized zinc, is the cause of brass founders' ague, it should be many times easier for a case to be developed where zinc is being boiled than where the zinc is at the low temperatures used in galvanizing. That this is true in industrial practice is very generally admitted.

Cryoscopy of the System Cu: Zn.—In considering the vapor tension of the most familiar zinc alloy, brass, factors other than that of simple solutions enter into the problem. Cryoscopic curves for the system Cu: Zn have been determined and show that the melting points of the alloy lie between that of either metal. Copper melts at 1083° C. (2), and zinc at 419.4° C. Gillett (1, p. 131) gives 75 Cu: 25 Zn a melting point of 920° C., while 60 Cu: 40 Zn melts at about 890° C. By increasing or decreasing the percentage of either metal the melting point can be altered at will. In practice this is not strictly carried out since it has been shown that, with certain definite proportions, alloys of optimum tensile strengths, ductility, hardness, etc., are formed. Furthermore, metallographical observations have demonstrated that all of the zinc and copper present are united as a true alloy or solid solution only under limited conditions. When thus united it is probably correct to treat the system as a simple solution. The excess copper or zinc may then be considered to exert its own independent effect in the estimation of vapor tensions. For our purposes it is sufficient to consider brass as a true solution in all cases and to ignore the heat of formation of Cu: Zn, which is probably not great.

VAPOR TENSION OF BRASSES

The boiling point for copper is about 2350° C. (3), as compared with 920° to 930° C. for zinc. If cold zinc is added to molten copper it will quickly be heated to a temperature in the neighborhood of its boiling point. If we suppose the copper to be at a temperature of 1150° C., Johnston's curves show it to have a vapor tension of only 0.002 mm. The tendency for copper oxides to form from copper vapor at this temperature is, therefore, negligible compared with the oxidation of the zinc vapor which would exert practically its full tension of 760 mm.

When the zinc is all melted and mixed with the copper — and this occurs rapidly — we have a system which, like alcohol and water, boils at a point between the boiling temperatures of the two constituents, the tension of the mixture being the sum of the partial tensions of the

two metals. Hansen (8) has made several vapor-tension determinations for various brasses, and these determinations, with others, have been brought together by Gillett (1, p. 126). In a curve shown in Figure 2, Johnston (9) has used these data for plotting, taking as abscissae the percentages of zinc in brass, and as ordinates, the ratio between the measured or calculated pressure, P, of the brass to the pressure, P', which the zinc alone would exert at the temperature in question. With this curve and his own vapor-tension calculations, Johnston (7) has also plotted the approximate vapor tensions of zinc in a number of brasses, the curves of which are reproduced in Figure 3. If, to these vapor-tension curves, we add that of copper, it will be seen that vaporization of this metal below a temperature of 1200° C. is too slight to be readable. This temperature is above that normally used in the melting and pouring of brass. Gillett (1, p. 259) believes that there is little or no copper in brass fumes from true volatilization, and that such as is found from fume analyses is due to mechanical entrainment with the zinc. This seems to be in accord with the theoretical evidence of the vapor-tension data.

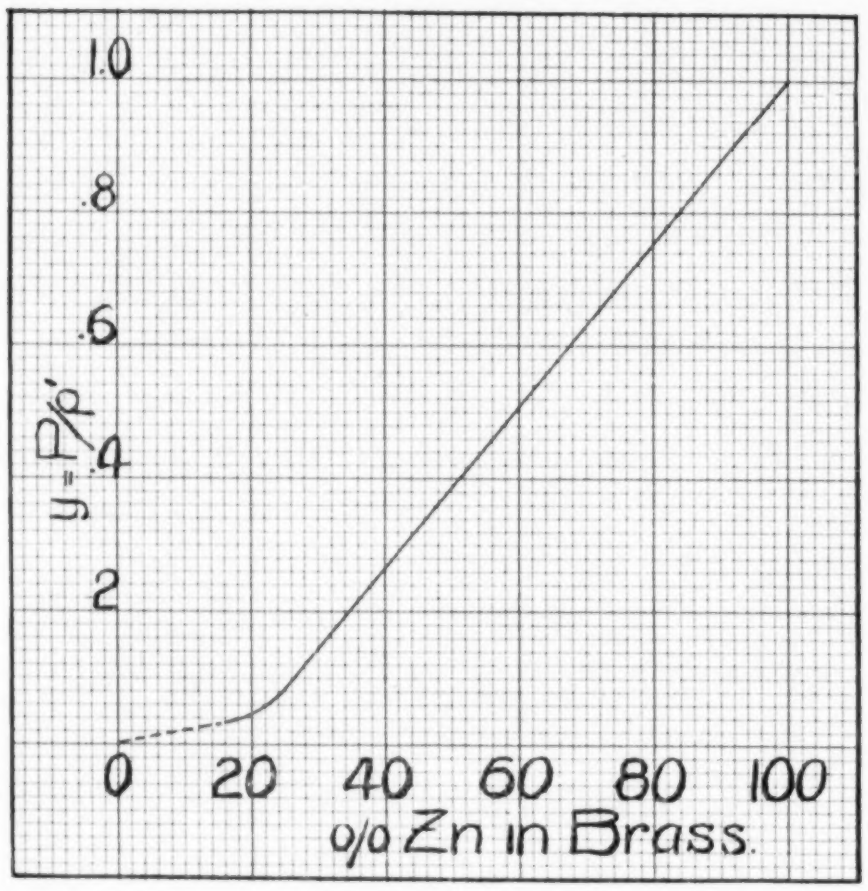

FIG. 2.—Ratios of the partial pressure of zinc in brasses to the pressures exerted by zinc alone (9).

If we consider brass to contain nothing but copper and zinc, Johnston's curves explain the greater evolution of zinc oxide from yellow brass with high zinc content than from the low zinc brasses. If it is desired to impoverish a given brass with respect to zinc, it is only necessary to keep the temperature sufficiently high to produce a requisite evolution of zinc-oxide fumes.

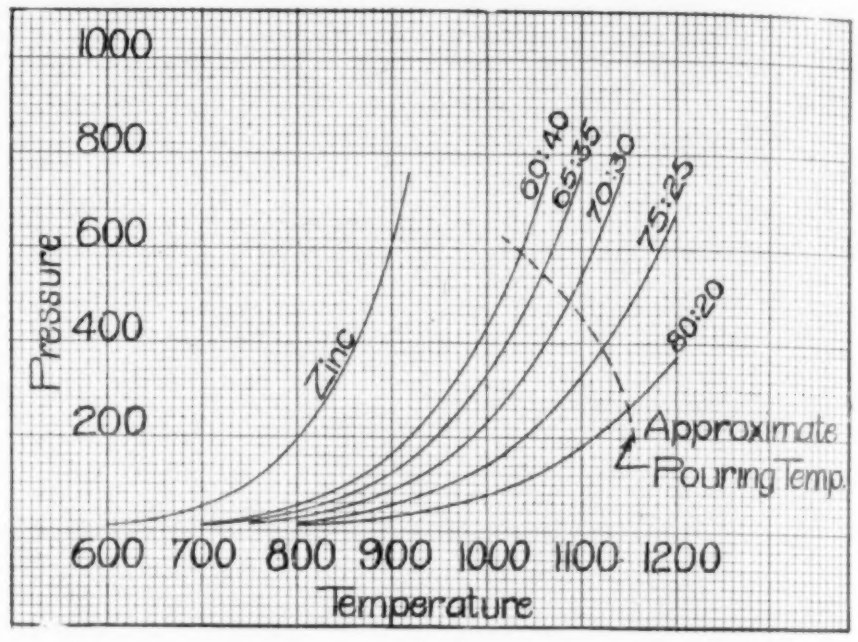

FIG. 3. — The approximate partial pressure of zinc from several brasses at various temperatures (9).

MANUFACTURE OF BRASS

In the manufacture of brass in gas-heated furnaces or crucibles, the molten metal is covered with a layer of charcoal or coke, to which a little sodium chloride is usually added. Gillett (1, p. 141) states that covers for the crucibles help to keep down volatilization of the zinc but that they are seldom used. When a crucible is removed from the fire, a certain amount of zinc is burned to the oxide as the zinc vapors rise from the molten mass. When the charcoal cover is skimmed off or a cover removed, there is a more rapid evaporation of zinc

vapor — just as there is a more rapid evaporation when the cover is taken off a pot of boiling water. The zinc vapor rises and is burned as fast as it comes into contact with air. The oxide formed is of extreme fineness and readily floats upward by virtue of the convection currents caused by the heat from the crucible.

If the brass contains cadmium, this metal will, by virtue of its greater vapor tension, be more readily volatilized and burned than is zinc. At the expense of a considerable amount of zinc, brass can be impoverished with respect to cadmium simply by keeping the brass at a relatively high temperature. Lead, with a lower vapor tension than zinc, and tin, with a tension greater even than copper, are often used in alloys with zinc and copper. Theoretically, their volatilization and oxidation follow these same general principles, and the composition of the oxide fumes from molten alloys containing a mixture of all four metals can be approximated by curves made as are those of Johnston for simple brasses.[4]

In the electric furnace these same principles apply. Much higher temperatures, particularly in arc furnaces, can be reached, and volatilization correspondingly increased. For this reason careful temperature control is perhaps even more essential than in gas-heated furnaces, but at the same time the manipulation of the temperature is facilitated.

Composition of Brass Fumes. — We are concerned only with fumes at temperatures at which they can enter the nose and mouth without producing injury due to heat alone. To breathe fumes containing unoxidized zinc vapors requires their inhalation before they have reached the air and been burned to the oxide. Obviously this is not to be considered. There appears no evidence that it is possible to breathe fumes containing unoxidized metallic zinc of sufficient fineness to float upward with the air currents. Gillett (1, p. 259) says, "It is unlikely that metallic zinc reached the lungs unoxidized", and this, in the writer's opinion, is putting the matter conservatively.

Analyses of brass fumes show the presence of the several metals entering into commercial brasses in quantities and types of compounds, such as chlorides and sulphates, which can only be explained independently of vapor-tension calculations. Sodium-chloride covers probably increase the volatility of copper, for example, by forming copper chlorides. With none of these are we concerned, however, since it has been clearly proved that the ague can be produced by the inhalation of zinc oxide alone, and only under very definite and sharply limited conditions.

Volatility of Zinc Oxide. — It has been claimed by Kowalke (11) that zinc oxide is appreciably volatile at 1240° C. and can be completely volatilized at 1300° C. Since we are not dealing with air even remotely approaching these temperatures, it is improbable that Kowalke's work has any bearing on the ague.

A Review of the Literature on the Toxicity of Zinc Oxide

Introductory.—In a critical study of the medical literature on zinc oxide, considered in the light of our modern knowledge of the rôle and importance of the physical aspects of particle fineness, a number of striking discrepancies are apparent. Numerous clinical and experimental studies on the ingestion of zinc oxide have proceeded almost side by

[4] Bassett (10) claims that this is not so in practice and that both cadmium and lead are more readily volatilized than is zinc.

side with studies of the systemic effects from the inhalation of freshly burned zinc vapor. Reference will be found — indeed, in the earliest reliable reports on the ague — to the fineness of the particles. In one report, which will be discussed later, it was noticed that, when ingested, zinc oxide produced by the wet method and that produced by the dry method differed in their physiological effect. That the microscope might throw some light on the cause of the discrepancies between the results produced by the inhalation of freshly burned zinc oxide and those produced by the ingestion of ordinary oxide as taken from a bottle, seems to have been utterly ignored by even the most recent investigators.

Reports on the occurrence of the ague in the smelting and refining of zinc ores containing lead, arsenic, etc., are limited. Rather generally these reports contain statements upon the probable effects of lead or other impurities, and intimate that the impurities are of more importance than the zinc. Occasionally there have appeared evidences of the systemic effects resulting from the inhalation of brass and other metallic dusts having been confused with the ague. Although such reports are the exception, they cannot be ignored.

The medical literature on zinc oxide may be conveniently grouped in five distinct classes, under which it will be treated in this report:

1. Accounts prior to 1845.
2. Systemic effects from zinc oxide whether given internally or used externally.
3. Systemic effects from the inhalation of freshly burned zinc oxide.
4. General hygienic effects in the smelting of zinciferous ores.
5. Systemic effects from the inhalation of powdered brass.

Groups 2 and 3 are the most important, but for the sake of their chronology the classes may best be treated in the order given.

Accounts Prior to 1845. — There is abundant historical evidence of the skill of the ancients in gilding and in the manufacture and working of bronze, brass, and other alloys. Reliable metallurgical accounts, however, are lacking. In their recent translation of Agricola's "De Re Metallica" (1546), Mr. and Mrs. Hoover (12, p. 354) state that brass was made prior to the Christian era. On zinc oxide they quote Dioscorides (12, p. 215) (13), who described the manufacture and recovery of *pompholyx* (zinc oxide) and stated that it appeared at first like "bubbles of water, afterward increasing in size, it looks like skeins of wool," *lana philosophica* (philosophers' wool).

Fourcroy's (14) French edition of Ramazzini's classic (1700) on industrial hygiene contains accounts of lead colic, and mentions the fumes from gilding in boiling off the mercury in the amalgams, but it gives nothing definite on brass fumes.

According to Tanquerel des Planches (15), Guyton de Morveau (16), in 1781, was the first to advocate the use of zinc white in place of lead white for the manufacture of paint. After this date, therefore, we should expect to find accounts of the manufacture of zinc oxide and the occurrence of the ague in this industry.

Patissier (17), in 1822, described the old process of amalgam gilding and stated that "the oxidized vapors of copper and zinc" produce "colic often accompanied by *de douleurs terribles.*" Thackrah (18), in 1831, mentioned symptoms about like those of the ague and caused by the inhalation of freshly burned oxide. For this reason he is frequently said to be the first to have

recognized the condition as an entity.

Werneck (19), in 1831, appears to have been the first to describe systemic effects from internal doses of zinc oxide. Busse (20), in 1837, is cited by Michaelis (21) as having made a futile attempt to cure an epileptic with zinc oxide. It was not until many years later that this treatment was abandoned.

Systemic Effects from Zinc Oxide Given Internally and Used Externally. — In 1847, Heller (22) published an account of the internal administration of measured doses (20, 60, and 120 grains per day) of zinc oxide suspended in sugar solution. Heller seems to have observed no systemic effects, and concluded that not only was the oxide physiologically inert and, therefore, useless as a medicine, but that it was quantitatively recovered in the feces as the oxide, and that none appeared in the urine.

Schlossberger (23), in the next year, took exception to Heller's results and analytical methods, and particularly to his statements on the inertness of zinc oxide. Schlossberger showed that the oxide was appreciably soluble in weak acids, such as lactic and acetic acids, and in ammonium chloride solutions; and that it could be digested or dissolved by such media as pepsin hydrochloride. He also mentioned the insolubility of albuminate of zinc.

Bouvier (24), in 1850, reported a case of so-called *colique de zinc* in a patient, 42 years of age, engaged in packing and handling zinc oxide. While the symptoms were rather more violent than those ordinarily reported, they showed the expected systemic reaction occurring on the ingestion of zinc oxide. No lead or arsenic was detected in the dust from the patient's body and clothes — nothing but zinc oxide.

These reports appeared at about the time that the manufacture of zinc oxide in Europe was receiving much impetus through its successful use as a substitute for white lead in paint. Lead colic was well known — so well known, indeed, that reports on the effects of zinc oxide may have received unconscious color owing to the contagious influence of the numerous reports on lead poisoning. A report by Flandin (25), in 1850, is quite typical of this period. He made up pastes of zinc oxide and lead sulphate and applied them to the shaved hides of dogs. Apparently no precautions were taken to prevent the dogs from licking themselves and thus swallowing the pastes. The dogs rubbed with the lead pastes died shortly, while those treated with zinc oxide showed no ill effects. Flandin, therefore, concluded that the oxide was harmless externally, and that its use as a white lead substitute was fully warranted on the basis of the respective toxicities of the two substances.

Landouzy and Maumené (26), in the same year, described systemic effects from zinc oxide dust in seven men handling galvanized iron wires which had become coated with a film of oxide. When clean wires were used no further effects were noticed. No analyses of urine or feces are recorded.

Michaelis (21), in 1851, was the first to report an analytical technic for the determination of zinc in tissues, and on this technic he based the value of his results and conclusions. He differentiated between zinc oxide prepared by burning zinc and that prepared by igniting the hydroxide, but gave rather meager substantiation of the alleged difference. Moderate doses of oxide were given to the rabbit, cat, dog, and horse, and analyses of urine and feces were made, followed by postmortem examinations. Following his investigations on animals Michaelis took mild doses of

oxide himself, and described the results. The systemic effects were carefully noted, and may be summarized in his conclusions that the oxide was harmless in small doses, that large doses produced pronounced and definite effects due to the solubility of the oxide in the weak acids of the stomach, and that the compound formed was governed by this acid content. Hydrochloric and lactic acids were suggested as being the chief agents in producing solutions of the oxide. Diet was claimed to be the governing factor in controlling the compound formed. Finally, he concluded that if zinc oxide was of use internally, which he did not claim was the case, it should be administered as the lactate, acetate, or some other comparatively inert salt, and should not be used as the oxide, in which form it can too readily be converted into the chloride. If the oxide was used externally, he believed that acidity could play an important rôle in rendering it toxic.

Tardieu (27), in 1852, described the manufacture of zinc oxide and, from the hygienic point of view, gave it a clean bill of health. Bouchut's (28) account was similar in this respect but he reported instances of the ague among men engaged in roasting zinc ores for making the oxide. Its occurrence, he said, was limited to those actually in the immediate vicinity of the furnaces, and the resulting malady was so trivial that it did not incapacitate the men the next day. Because zinc oxide was used internally as a medicine he believed that it could result in no harmful effects if breathed or ingested. Marcet's (29) report, in 1855, should be considered as one of this group because he too believed that zinc oxide was beneficial as an internal medicine and as such was effective in cases of nervous disorders and epilepsy. He advocated doses of 30 grains daily and claimed that there were no ill effects except "slight sickness" and "constipation." This may be considered as quite typical of the general view then prevailing on the medical use of zinc oxide.

Of the systemic effects of large doses there are several examples. Spillmann (30) reported an instance of a patient's taking as much as 10 gm. in water. The effects were naturally violent but seemingly not fatal. D'Amore, Falcone, and Maramaldi (31) gave large doses of zinc oxide to dogs and furnished post-mortem studies which showed a pronounced and vigorous effect on all the organs examined. Not only were the doses administered excessive, but they were unaccompanied by any sort of check on the diet. Instead of grading the doses by some method consistent with the animal's body weight, as was done by Michaelis, they gave as much as 1 gm. per day at the start and then diminished the quantity to 0.1 gm. after a few doses of the larger amount.

Sacher (13), in 1893, presented an extensive report on the action of zinc salts. He concluded that both the oxide and the carbonate were inert in small doses but that they exercised notable systemic effects in large doses. Lehmann's (32) investigations with zinc carbonate resulted in his concluding that it was comparatively inert. This salt is perhaps sufficiently like the oxide in its general solubility characteristics and inertness to justify their comparison on the basis of their physiological action. In making this comparison, however, the carbonate should be considered on the basis of the chemically equivalent amount of oxide. Converting Lehmann's figures of an average dose to the dog of 44 mg. of oxide per day per kilo body weight into the chemically equivalent amount of oxide gives

a figure of 28.5 mg. per day.[5] On this basis Lehmann's doses were less than the excessive doses of d'Amore and his co-workers, and about like those of Michaelis. The fact that the effects which he produced appeared negligible is probably thus accounted for and this finding does not conflict with the findings of Michaelis noted forty-six years previously. Stepp (33), in 1917, reported a case which, if there are no other factors entering in, is unique. To a patient suffering from eczema he prescribed the use of zinc oxide salve. Over a period of eighteen days 250 gm. were applied. Then the patient returned to the clinic, complaining of headache and difficulty in breathing. He showed a high pulse rate and had zinc in his urine. After twelve days in bed his condition was again normal. Stepp apparently did not consider the possibility of the patient's getting the oxide into his mouth through the agency of his hands, as is the ordinary course of events in the handling of white lead, and offered no explanation of the effects which undoubtedly seem to have been due to zinc oxide. This, however, is but a single instance and, so far as the writer is aware, the only one of its kind cited in the literature.

Bigelow (34), Salant, Rieger, and Treuthardt (35) have investigated the distribution and elimination of zinc salts. While their work has perhaps an indirect bearing only on the subject matter of this paper, it is of interest to note their conclusion that the bulk of the zinc is eliminated in the feces, traces only being found in the urine.

Turner (36) has reported what he styles as "occupational dermatoconiosis" produced from frictional skin infection with zinc oxide. From his own statements it appears that the infections, which were of a mild and unimportant type, were such as could be produced by excessive rubbing with almost any fine, dry inert powder. Zinc oxide and "its impurities" are considered as non-poisonous by Turner. His article, therefore, has no bearing on the toxicity of zinc oxide and is of no importance in this connection.

Systemic Effects from Inhalation of Freshly Burned Zinc Oxide.—The cases of the so-called ague, which have been reported in the literature, may be grouped under this class. Since zinc oxide produces its most pronounced toxic effect when inhaled in the freshly burned state, this group is the most important. There are a great many reports of the occurrence of the ague. In spite of its general prevalence it was many years before the cause was positively identified. Many theories were advanced and, because zinc oxide was used as an internal medicine until a comparatively recent date, early investigators were loath to believe that it could be the cause of any systemic disorders. Since the ague was noted mainly in the brass industries, it was natural that copper should be frequently implicated as guilty in part, at least, of causing the malady to which men in poorly ventilated brass foundries were subject.

Beginning in 1845 there appeared a series of reports for the most part much alike and in general quite accurate. Blandet (37) furnished a good description of the method in which zinc oxide is produced in pouring brass, noted its fineness, pointed out that the ague was too well understood by the operatives to warrant their calling in medical assistance, and described the symptoms and course of the malady about as it is described in accounts appearing in recent times. Guérard (38)

[5] One gm. of zinc carbonate is chemically equivalent to 0.649 gm. of zinc oxide.

discountenanced Blandet's hypotheses and rather naïvely attributed the causes to the drinking of too many lukewarm aqueous beverages. Then followed in rapid succession a series of reports which, in the main, agreed with Blandet. All advocated better ventilation as the surest remedy. One suggested that perhaps copper together with the zinc was the cause; another showed that lead was in the brass being cast. The authors included in this series were: Lévy (39) in 1845; Reboulleau (40) in 1847; Gardner (41) in 1848, who gave the first report in the United States; Chevallier and Boys de Loury (42) in 1850; Greenhow (43) in 1862; and Schnitzer (44), who presented the first German account. Because he was more emphatic, or perhaps because he wrote in English, Greenhow is the most frequently cited of this group.

In the original edition of his book in 1871 and in two subsequent editions, Hirt (45) suggested that copper and zinc together were responsible for the ague, and that the fact that the malady was not encountered in the ordinary metallurgy of zinc was proof of this hypothesis.

Popoff (46), in 1873, reported an unusual case. His patient was moved from other work to casting bronze and brass. Soon he became subject to attacks much resembling the ague, and after several weeks reported at Popoff's clinic. Together with other lesser disorders the patient had a pronounced internal tumor which may have caused him to describe his feelings in stronger terms than would have been used by a normal healthy individual. The interesting point is that Popoff found zinc in the man's urine a month and a half after he had been away from the foundry. Unfortunately, no control of diet was exercised.

Beginning in 1875 another distinct group of articles appeared, the authors of which cited from the existing literature but added nothing new: Layet (47) in 1875, Eulenberg (48) in 1876, Buck (49) in 1879, Lloyd (50) in 1880, and Poincaré (51) in 1886.

A good account of the ague was published by Simon (52), in 1888, and has been cited frequently by later writers. He believed that the malady was in no way chronic, that an immunity could be developed, and that both copper and zinc were responsible. Following Simon's article several more or less conventional and unimportant reports were published by various authors: namely, Arlidge (53) in 1892, Czajkowski (54) in 1893, Heinzerling (55) in 1894, Maher (56) and Oppenheimer (57) in 1895, Villaret (58) in 1896, and Sommerfeld (59) in 1898.

Hohmann (60), working with Lehmann, endeavored to produce the ague in animals by subjecting them to the fumes of freshly burned zinc oxide from both brass and zinc. While the procedure was a distinct step in the right direction their investigations did not bring forth their best results until a few years later. A copy of their questionnaire to brass founders is included in Hohmann's paper.

After Hohmann's report two unimportant contributions by Moyer and Lavin (61) and Sicard (62) appeared. Sigel (63) published an extensive report in 1906, in which he agreed with Lehmann's and Hohmann's conclusions that zinc was the cause of the ague. On its permanent effects he cited Popoff (46) who, as has already been brought out, gave a report on a brass founder afflicted with far more serious ills than the ague. Sigel stood beside the molds while castings were poured, caught the

ague, and described its progress in himself.

Lehmann (64), in 1906, showed that the ague could be produced from the burning of zinc alone. He and four others, one of whom was a caster who was said to be unusually susceptible, remained in a room where Merck's chemically pure zinc was vaporized and burned. Analysis of the room air showed the presence of 0.1 to 0.4 mg. of zinc oxide per liter. No zinc vapor or zinc peroxide was found. In this article Lehmann states that he can offer no explanation of the mechanism by which zinc oxide does harm, but suggests the possibility of the destructive action of the fine oxide on the epithelial cells of the respiratory passages. In this connection he has pointed out his repeated failures to produce analogous effects by the tracheal injection of zinc oxide. Lehmann's experiments have since received such wide recognition that they may be considered as generally accepted. In apparent ignorance of Lehmann's work, Perry (65), in 1907, claimed that no effects resulted from inhaling freshly burned zinc oxide, as he had done it frequently without suffering any harm. It was his opinion, therefore, that zinc oxide could not be the cause of the ague. He rather believed that the small amount of arsenic contained in commercial spelter was the cause.

Graeve (66), in 1907, described two cases in which the symptoms were so violent that he hesitated in placing the blame on zinc, and was of the opinion that further confirmation, which is nowhere furnished, was needed to settle the matter. Weyl (67) reviewed the existing opinions and gave examples of the prevalence of the ague in poorly ventilated shops which he compared on the basis of the heights of the ceilings, this giving a rough index of the adequacy of the ventilation. Roth's (68) account is quite in keeping with literature of that period and contains no new information.

In 1910, Lehmann (69) described more fully his earlier experiments (64) in which he showed that the ague could be produced by burning pure zinc.

Arnstein (70) has furnished a series of clinical reports on the effects experienced by himself and his assistants as a result of their having stood near the molds when brass, with zinc content of about 25 per cent., was being cast. He determined the zinc-oxide content in the air inhaled as 0.23 mg. per liter, which is a close approximation to Lehmann's (64) earlier figure of 0.1 to 0.4 mg. per liter. Arnstein found traces of zinc in the urine and appreciable amounts in the feces.

Kisskalt (71) claims that a more marked similarity exists between the effects produced by the inhalation of various heavy metal vapors than between those produced by introducing these same metals into the system by other means. Subcutaneous injections of zinc salts are said to cause a rise in body temperature experimentally demonstrable in animals. On this basis an analogy is drawn between the systemic effects of zinc, mercury, and copper.

Since the early experiments of Michaelis (21), von Jaksch's (72) rather extensive investigation is the first in which there is an attempt to explain the difference between the effects of ingesting ordinary zinc oxide and inhaling freshly burned oxide. He believes, like Michaelis, that the oxide is so insoluble that it must be converted into the chloride or lactate before it makes its action felt. Furthermore, he attempts to classify doses according to size and to the effects produced.

Bargeron (73) and Rambousek (74) gave the usual accounts of the ague, Pfender (75) mentioned its occurrence in oxyacetylene brazing, and Thompson (76) differentiated between the effects of inhaling metallic dusts and the effects of inhaling fresh zinc oxide fumes. Thompson's article contains some rather unfortunate misstatements on the volatility of copper, copper oxide, and zinc oxide.

Hayhurst (77) has written extensively on the ague. From the medical point of view his accounts are admirable and show evidence of much study and personal investigation into the general hygienic conditions prevailing in brass foundries. From the metallurgical and chemical side there are many inaccuracies. The hypothesis of zinc carbonyl as the cause of the ague has already been shown by Gillett (1, p. 259) to be totally untenable. Hayhurst's comparison or analogy between zinc oxide and zinc chloride on the basis of their hygroscopicities is entirely out of keeping with the well-known and totally different solubility characteristics of the two compounds. What he says of the searing action of zinc oxide would apply equally well to any other dry inert powder.

Oliver (78), in his "Diseases of Occupation" (1916), maintains his hypothesis of 1902 that zinc and copper together are responsible for the ague. Riesman and Boles (79) quote from Oliver in giving a review of the purely medical and hygienic aspects of the ague. Like Oliver they maintain that it can be effectively prevented by adequate ventilation.

Lehmann's (80) recent book contains a well-summarized account of his previous investigations and a clear exposition of his theory of the action of zinc oxide on the epithelial cells and bacteria of the respiratory passages.

Rost (81) discusses the general distribution of zinc in plant and animal life and points out the necessity of diet controls in considering the zinc content of urine and feces in men or animals living on normal mixed diet. In experiments with animals Rost (82) later shows that zinc oxide can be taken up in the lungs and ultimately excreted in the urine. Three dogs and two rabbits were placed together over the same mold in a brass foundry so that all inhaled air of about the same zinc-oxide content. One dog had been tracheotomized so that he could take in zinc oxide by the stomach alone; another had his esophagus closed off so that the zinc oxide could enter the lungs only. They showed fairly comparable systemic effects as to temperature, and both showed zinc in the urine with larger amounts, of course, in the feces. In themselves, Rost and his assistant had no difficulty in producing the ague, which they describe in the usual terms. Zinc was found in their urine for several days after exposure to the fumes.

General Hygienic Effects in Smelting of Zinciferous Ores.—While of interest from the point of view of general hygiene in ore smelting and metallurgical operations, reports in the literature coming under this classification are of little importance in considering the toxicity of zinc oxide. It is obvious that if we are dealing with the systemic effects of zinc oxide, the presence of metals other than zinc, unless in very definitely known amounts and under conditions thoroughly understood, renders the implication of zinc as the cause of possible poisonings a matter of extreme doubt. For this reason too much weight should not be given to reports of general smelting and refining of zinc.

In 1879 an article appeared by Schlockow (83), in which he rather incriminated zinc for certain ill effects noted among metallurgical workers. Tracinski's (84) account, in 1888, has in reality little to do with zinc, although it is frequently cited. Seiffert (85), Wutzdorff (86), and Frey (87) have all written on this general subject. The subject matter of their articles is really irrelevant to that under discussion and their papers are mentioned only because they are so frequently cited in the literature on zinc and the ague.

Systemic Effects from Inhalation of Powdered Brass.—In the early accounts of the ague references are sometimes made to systemic effects from the inhalation of brass powder, such as results from grinding and buffing of brass objects. Some writers have distinguished the ague by its lack of periodicity, the so-called *brass poisoning* being said to exhibit a type of periodicity as its outstanding feature. Regardless of the accuracy of either statement, effects from the inhalation of powdered brass and like copper or zinc alloys, whether serious or trivial, chronic or irregular, are not effects from zinc oxide and should not be confused with brass founders' ague. A typical report is that published by Hogben (88) in 1887. He defends the action of zinc oxide on the grounds that it has proved beneficial to patients, and believes that the "copper green line" exhibited by his patients, who were employed in brass-finishing work, was sufficient evidence that copper was to blame. Later reports by Murray (89) and Pietrowicz (90) are much like that of Hogben. These reports are mentioned only because the systemic effects which they describe have quite frequently been confused with the ague.

Comparison between Systemic Effects of Freshly Burned Zinc Oxide and of Normal Zinc Oxide Powder

From the physico-chemical and metallurgical standpoints there is no evidence whatever that the substance produced by burning vaporized zinc is anything but zinc oxide. Attempts to show the presence of any other zinc compounds resulting from this oxidation have given negative results.

That there is a very definite physiological difference in the effects produced by inhaling fumes of freshly burned zinc oxide and those produced by normal zinc oxide powder is shown by the numerous reports on the ague and the comparatively rare instances of systemic disturbances among men handling the powder. The recorded attempts to produce the ague artificially by the injection or ingestion of oxide powder have invariably given negative results. Well-defined systemic effects from swallowing oxide have been repeatedly produced and show that the magnitude of the effects vary in proportion to the amount of oxide taken into the system—small doses gave negligible results and large doses produced gastrointestinal disorders and nephritis. In no instances are there recorded evidences of chills or fever. Inhalation of freshly burned oxide, no matter how produced, has invariably given rise to the ague and the characteristic symptoms with chills and fever. In both cases zinc is found in the urine and feces.

Comparison of doses of freshly burned oxide inhaled with doses of normal oxide powder ingested, on a weight basis, shows that doses of the powder have been given which are many times greater than the amounts taken into the

system by remaining from twenty to thirty minutes in close vicinity to a source of freshly burned oxide and breathing normally. From Arnstein's (70) figures of 0.23 mg. of zinc oxide per liter of air, in one hour, a normal individual at rest would inhale approximately 120.0 mg. of oxide.[6] Doses of oxide powder far exceeding this in weight have been given without producing anything like the same results.

Much of the oxide in an ordinary breath of air containing oxide of either type is undoubtedly mechanically stopped on its passage to the lungs, and, unless ejected by expectoration or coughing, ultimately reaches the stomach. The oxide which reaches the lungs must either remain there, be phagocytised and pass out by the lymph, or pass into the blood capillaries of the lung. Some may find its way up the trachea again and be swallowed.

That portion of the zinc, whether ingested or inhaled, appearing in the urine represents oxide which has been chemically acted upon and actually dissolved. Otherwise it would not appear in the urine. The zinc which is found in the feces is, in all probability, unchanged zinc oxide and has been truly inert—in the purely chemical sense. The ratios of the zinc appearing in the urine and feces are, from the accounts in the literature, varying quantities, as would be expected. The amount in the urine is invariably trifling compared to that in the feces. Whether or not the zinc in the urine represents all that which has produced a systemic effect is a matter of speculation on which present knowledge is insufficient.

Michaelis (21) explains the physiological effect of zinc oxide ingestions on the ground of zinc chloride formation. Lehmann (64) (69) (80) explains the ague effects from freshly burned zinc oxide as due to the destruction of the epithelial cells of the respiratory tract. Michaelis' explanation appears highly probable and would account for the effects noticed from oxide ingestions. Lehmann's theory places the fresh zinc oxide on the same footing as any other dry inert insoluble powder.

Particle Size.—It has been shown by Wells and Gerke (91) that particles of the order of 1 micron and less do not obey Stokes' law governing rates of settling in such media as air. This observation applied to individual and dispersed tobacco smoke particles which they estimated to be 0.273 microns in size. They found that time appeared to be a factor in the rate of particle flocculation, and plotted frequency curves to illustrate this point.

In the measurement and counting of small particles such as zinc oxide, Green (92) has pointed out the profound error caused by ignoring flocculation. He found zinc oxide particles to be of the order of 0.534 microns, or about twice the size that Wells and Gerke recorded for tobacco smoke particles. That zinc oxide, as taken from a bag or bottle, is flocculated to a high degree, will be disputed by no one who has ever compared it, even macroscopically, with the freshly burned oxide fumes.

Factors Affecting Particle Flocculation.—It is a matter of daily observation that humidity exerts a great influence in diminishing air dustiness. Katz, Longfellow, and Fieldner (93) have pointed out the necessity of using silica dust dried at a high temperature and dry air in the artificial production of dust clouds. This seemingly elementary but important fact has been con-

[6] This is allowing 500 c.c. per breath and seventeen breaths per minute. For a man undergoing vigorous physical exercise this quantity would be increased about two or three times.

firmed repeatedly by the writer with other fine powders much like silica in their adsorptive properties. Whether flocculation of the particles is caused by the adsorption of moisture alone, by electrostatic effects, or is an expression of some other effect, such as surface tension, has not, so far as the writer is aware, been definitely proved. On the facts, however, there can be no doubt—humidity exerts a marked effect on promoting particle flocculation. What the optimum conditions for producing flocculation are has yet to be determined and appears to be one of the most needed factors in the handling of dust problems.

Thoroughly dried dusts with which the writer has worked behave quite differently from those containing adsorbed moisture. The former are more dispersed and float about in the air much more readily and, on passing through glass or other tubes, have little tendency to adhere to the sides of the tube, even if there are numerous sharp bends. Flocculated particles, possessing the normal adsorbed moisture content, tend to deposit themselves on the walls of tubes and particularly at points where they are forced to undergo a marked change in direction.

Zinc oxide, freshly produced by the oxidation of vaporized zinc, is in the optimum condition of dispersion, and is inevitably dry. Consequently it is in the optimum condition to pass through the nose or mouth into the trachea and down into the lungs without coming into contact with the tracheal walls. If the particles reach the alveoli in the freshly burned dispersed state, they offer the maximum surface for phagocytosis and ultimate solution. When flocculated, they inevitably offer relatively less surface and are consequently less readily dissolved, since the speed with which particles are dissolved is a function of their surface area.

A Possible Explanation of Difference in Physiological Action of Zinc Oxides

Dispersion and absence of adsorbed moisture would appear, then, to be the main points of difference between the zinc oxide which produces the ague and that which does not. That there is a marked physical difference between these two types of oxide and that this difference is utilized commercially in oxide manufacture and collection is attested to by Breyer (94). If this physical difference in the state of the particles explains the difference in their physiological effects, it should be possible to show the degree and rate at which the factors producing flocculation gradually or abruptly bring the freshly burned oxide into the state in which it no longer produces the ague. This appears to be actually carried out in the manufacture of zinc oxide. Men working near the furnaces where the oxide comes off in the freshly burned state are subject to the ague; those in industries where this same oxide is handled and where zinc oxide is also inhaled do not complain of the ague. In both cases it is chemically zinc oxide and virtually pure. In the freshly burned state it is made up of dispersed particles. In the other state it is largely flocculated, undoubtedly lower in temperature, and contains some adsorbed moisture. Considered in this light the toxicity of zinc oxide is of interest and importance to the manufacturer, the clinician, and the industrial hygienist alike. Considered simply as a malady which can be avoided by adequate ventilation, the brass founders' ague appears to be of minor importance. In the latter case it is

very properly placed under the domain of preventive medicine, and its occurrence is ascribed to carelessness. In the former classification it can be regarded as a convenient link between fumes and dusts, and as such it offers an interesting and important problem on the effects of humidity, temperature, particle size, and flocculation on the collection of dust particles. This phase of the problem will form the subject of a future paper.

Summary

The physio-chemical factors governing the formation of zinc oxide are discussed, the conditions under which zinc oxide produces the brass founders' ague are described, and the literature on the toxicity of zinc oxide is reviewed. A distinction is drawn between the physical states of zinc oxide as inhaled from the burning of vaporized zinc and oxide powder of which the particles have become flocculated. On the basis of this difference in physical states, a possible explanation of the difference in physiological effects of the two types of oxide is offered.

BIBLIOGRAPHY

1. Gillett, H. W.: Brass-Furnace Practice in the United States. U. S. Bur. Mines, Bull. 73, 1914.
2. Tables Annuelles Internationales de Constantes et Données Numériques, 1913-1916, *4*, Part 1. Paris, Gauthier-Villars et Cie.; Cambridge, Cambridge University Press; Chicago, University of Chicago Press, 1921.
3. Ruff, O., and Bergdahl, B.: Die Messung von Dampfspannungen bei sehr hohen Temperaturen nebst einigen Beobachtungen über die Löslichkeit von Kohlenstoff in Metallen. Ztschr. f. anorg. Chem., 1919, *106*, 76.
   Berthelot, D.: Sur les points d'ébullition du zinc et du cadmium. Compt. rend. Acad. d. sc., 1900, *131*, 380.
4. Richards, J. W.: Metallurgical Calculations. New York, McGraw-Hill Book Co., 1917, Part 1, pp. 63 and 88.
5. Hofman, H. O.: Metallurgy of Zinc and Cadmium. New York, McGraw-Hill Book Co., 1922.
6. Breyer, F. G., Singmaster, J. A., and Hall, A. E.: Manufacture of Zinc Oxid. U. S. Patent No. 1,322,088.
   Singmaster, J. A., Breyer, F. G., and Bunce, E. H.: Manufacture of Zinc Oxid. U. S. Patent No. 1,322,142.
7. Johnston, J.: The Vapor Pressure and Volatility of Several High-Boiling Metals—A Review. Jour. Indust. and Engin. Chem., 1917, *9*, 873.
8. Hansen, C. A.: The Vapor Tension of Zinc from Brass. Tr. Am. Inst. Met., 1912, p. 111.
9. Johnston, J.: The Volatility of the Constituents of Brass. Tr. Am. Inst. Mining and Metall. Engineers, 1919, *60*, 416; Jour. Am. Inst. Metals, 1918, *12*, 15.
10. Bassett, W. H.: Zinc Losses. Jour. Indust. and Engin. Chem., 1912, *4*, 167.
11. Kowalke, O. L.: The Volatility of Zinc Oxide. Tr. Am. Electrochem. Soc., 1912, *21*, 557. See also Hofman (5) page 36.
12. Hoover, H. C., and Hoover, L. H.: Translation of Agricola's De Re Metallica. London, The Mining Magazine, 1912.
13. Sacher, A.: Zur Kenntniss der Wirkung der Zinksalze. Arb. d. pharm. Inst. zu Dorpat, 1893, *9*, 88-152.
14. De Fourcroy: Essai sur les maladies des artisans. French edition of Ramazzini's De Morbis Artificum Diatriba. Paris, A. Delahays, 1855.
15. Tanquerel des Planches, L.: Traité des maladies de plomb ou saturnines. Paris, 1839.
16. Guyton de Morveau: Ann. des Arts et Manufactures, 1781, *4*. Cited from Tanquerel des Planches (15).
17. Patissier, P.: Traité des maladies des artisans, et de celles qui résultent des diverses professions. Paris, J.-B. Baillière, 1822, p. 34.
18. Thackrah, C. T.: The Effects of the Principal Arts, Trades, and Professions, and of Civic States and Habits of Living, on Health and Longevity. Philadelphia, 1831 (from London edition).
19. Werneck: Erscheinungen, welche das Zincum oxydatum album oder Flores Zinci bei gesunden Menschen hervorbrachte. Med.-chirurg. Ztg., 1831, *3*, 317.
20. Busse: Casper's Wchnschr., 1837, No. 19. Cited from Michaelis (21).

21. Michaelis, A.: Die physiologischen Wirkungen des Zinkoxyds. Arch. f. physiol. Heilkunde, 1851, *10*, 109.
22. Heller, J. F.: Untersuchungen des Harns und der Fäces nach dem innerlichen Gebrauche des Oxydum Zinci. Arch. f. physiol. u. path. Chem., 1847, *4*, 233.
23. Schlossberger: Zur Erläuterung der Wirkungen des Zinkoxids. Arch. f. physiol. Heilkunde, 1848, *7*, 589.
24. Bouvier: Empoisonnement par l'oxyde de zinc (Colique de zinc). Gaz. d. hop., 1850, S. 3, *2*, 232.
25. Flandin, C.: Expériences comparatives concernant les effets de l'oxyde de zinc, du carbonate, et du sulfate de plomb sur l'économie animale. Compt. rend. Acad. d. sc., 1850, *30*, 571.
26. Landouzy and Maumené: De l'intoxication zincale observée chez les ouvriers tordeurs de fils galvanisés. Gaz. méd. de Par., 1850, S. 3, *5*, 409.
27. Tardieu: Dictionnaire d'hygiène publique et de salubrité. 1852, *3*, 701; *2*, 20.
28. Bouchut, M. E.: Mémoire sur l'industrie et l'hygiène de la peinture au blanc de zinc. Ann. d'hyg., 1852, *47*, 5.
29. Marcet, W.: On the Treatment of Affections of the Nervous System with Oxide of Zinc. Assn. Med. Jour., 1855, N.S. *3*, 1045.
Waterman, S.: On the Therapeutical Employment of Oxide of Zinc. Am. Med. Month., 1861, *16*, 160.
30. Spillmann: Accidents toxiques à la suite de l'ingestion d'une certaine quantité de poudre d'oxyde de zinc. Rev. méd. de l'est, 1883, *15*, 147.
31. D'Amore, L., Falcone, C., and Maramaldi, L.: Action toxique et altérations anatomiques produites par l'ingestion de l'oxyde de zinc. Mém. Soc. de biol., 1892, S. 9, *4*, 335.
D'Amore, L.: Sur l'intoxication expérimentale par l'oxyde de zinc. Semaine méd., 1892, *12*, 456.
32. Lehmann, K. B.: Einige Beiträge zur Bestimmung und hygienischen Bedeutung des Zinks. Arch. f. Hyg., 1897, *28*, 291.
33. Stepp, W.: Ueber Zinkvergiftung. Med. Klin., 1917, *13*, Part 2, 1272.
34. Bigelow, W. D.: The Elimination of Zinc and Tin. Research Lab. Nat. Canners' Assn., Bull. 2, Aug., 1914. Abstracted in Jour. Am. Med. Assn., 1918, *71*, 748.
35. Salant, W., Rieger, J. B., and Treuthardt, E. L. P.: The Distribution and Elimination of Zinc and Tin in the Body. Jour. Biol. Chem., 1918, *34*, 463.
36. Turner, J. A.: Occupational Dermatoconiosis among Zinc Oxide Workers. U. S. Pub. Health Ser., Public Health Rep., 1921, *36*, 2727.
37. Blandet: Colique de cuivre. Ann. d'hyg., 1845, *33*, 461. Effets des vapeurs de zinc sur l'économie animale. *Ibid.*, p. 462. Du délire produit par l'inspiration des vapeurs d'oxyde de zinc. *Ibid.*, 1845, *34*, 222.
38. Guérard: Sur les effets des vapeurs de zinc, opposés à ceux des boissons aqueuses, prises avec excès. Ann. d'hyg., 1845, *34*, 224.
39. Lévy, M.: Traité d'hygiène publique et privée. Paris, J.-B. Baillière, 1845, Vol. 2, p. 782.
40. Reboulleau: Sur l'intoxication produite par les vapeurs d'oxyde de zinc. Compt. rend. Acad. d. sc., 1847, *25*, 451.
41. Gardner, A. K.: An Account of a Disease peculiar to the Workmen in Brasscock Foundries. New York Med. Jour., 1848, *10*, 210.
42. Chevallier, A., and Boys de Loury: Mémoire sur les ouvriers qui travaillent le cuivre et ses alliages. Ann. d'hyg., 1850, *43*, 337.
43. Greenhow, E. H.: Brass-Founders' Ague. Med. Chirurg. Tr., 1862, *45*, 177. See also Med. Times and Gaz., 1862, *1*, 227.
44. Schnitzer: Fieber bei Messinggiessern. Preussische med. Ztg., 1862, p. 197.
45. Hirt, L.: Die Krankheiten der Arbeiter. Breslau, Ferdinand Hirt, 1871, Part 1, 91; 1873, Part 2, 165; 1875, Part 3, 82, 83, 182.
46. Popoff, L.: Ein Fall von chronischer Vergiftung mit Zinkoxyddämpfen und Experimente über die Wirkung einiger antifermentativer Mittel. Berl. klin. Wchnschr., 1873, *10*, 49.
47. Layet, A.: Hygiène des professions et des industries. Paris, 1875.
48. Eulenberg H.: Handbuch der Gewerbehygiene. Berlin, 1876, p. 720.
49. Buck, A. H.: A Treatise on Hygiene and Public Health. New York, Wood, 1879, pp. 19-20.
50. Lloyd, J. H.: The Diseases of Occupations. Philadelphia, 1880, pp. 373-381.
51. Poincaré, L.: Traité d'hygiène industrielle. Paris, G. Masson, 1886, p. 278.
52. Simon, R. M.: Remarks on Brassworkers' Diseases. Brit. Med. Jour., 1888, *1*, 887.
53. Arlidge, J. T.: The Hygiene, Diseases and Mortality of Occupations. London, Percival & Co., 1892, p. 448.
54. Czajkowski, J.: Zinkvergiftung. Abstracted from Gaz. lek. in Jahresb. ü. d. Leistung. in d. ges. Med., 1893, *1*, 575.
55. Heinzerling: Gewerbehygiene. 1894, *8*, 755.
56. Maher, S. J.: Spelter Shakes. New York Med. Jour., 1895, *62*, 792.
57. Oppenheimer, A. R.: Report of a Case of Brassfounder's Ague. Bull. Johns Hopkins Hosp., 1895, *6*, 48.
58. Albrecht, H.: Handbuch der praktischen Gewerbehygiene mit besonderer Berücksichtigung der Unfallverhütung. Berlin, R. Oppenheim, 1896, Part 5, p. 779.

59. Sommerfeld, T.: Handbuch der Gewerbekrankheiten. Berlin, Oskar Coblentz, 1898, p. 480.
60. Hohmann, G.: Studie über Giessfieber. Würzburg, 1903.
61. Moyer, H. N., and Lavin, J. M.: Chronic Brass Poisoning—Brass-Workers' Ague. Medicine, 1904, *10*, 335.
62. Sicard, M. H.: Copper and Zinc Poisoning—Brass Poisoning. Med. Rec., 1905, *68*, 209.
63. Sigel, J.: Das Giessfieber und seine Bekämpfung mit besonderer Berücksichtigung der Verhältnisse in Württemberg. Vrtljschr. f. gerichtl. Med., 1906, *32*, 174, 384.
64. Lehmann, K. B.: Ueber das Giessfieber. Verhandl. d. Gesellsch. deutsch. Naturforscher und Aertze, 1906, Part 2, Section 2, 78, 362; Chem. Ztg., 1906, *30*, Part 2, 940.
65. Perry, S. H.: Brass-Workers' Disease. Med. Brief, 1907, *35*, 414.
66. Graeve, O.: Beitrag zur Bedeutung des Giessfiebers in der Gewerbe-Hygiene. Vrtljschr. f. gerichtl. Med., 1907, *33*, 370.
67. Weyl, T.: Handbuch der Arbeiterkrankheiten. Jena, Gustav Fischer, 1908, pp. 112-115.
68. Roth, E.: Kompendium der Gewerbekrankheiten und Einführung in die Gewerbehygiene. Berlin, Richard Schoetz, 1909, p. 61.
69. Lehmann, K. B.: Studien über technisch und hygienisch wichtige Gase und Dämpfe: XIV. Das Giess- oder Zinkfieber, Arch. f. Hyg., 1910, *72*, 358.
70. Arnstein, A.: Beitrag zur Kenntnis des Giessfiebers. Wien. Arb. a. d. Gebiete d. soz. Med., 1910, p. 49.
71. Kisskalt: Ueber das Giessfieber und verwandte gewerbliche Metalldampfinhalationskrankheiten. Ztschr. f. Hyg., 1912, *71*, 472.
72. Von Jaksch, R.: Die Vergiftungen. Wien und Leipzig, Alfred Hölder, 1910, p. 167.
73. Bargeron, L.: Note sur la fièvre des fondeurs. Ann. d'hyg., 1913, S. 4, *19*, 82.
74. Rambousek, J.: Industrial Poisoning from Fumes, Gases and Poisons of Manufacturing Processes. English translation by T. M. Legge. London, Edward Arnold, 1913, p. 151.
75. Pfender, C. A.: Brazier's Disease, Brass-Founder's Ague, or Acute Brass-Poisoning. Jour. Am. Med. Assn., 1914, *62*, 296.
76. Thompson, W. G.: The Occupational Diseases. Their Causation, Symptoms, Treatment and Prevention. New York and London, D. Appleton & Co., 1914, p. 169.
77. Hayhurst, E. R.: Occupational Brass Poisoning. Tr. Chicago Path. Soc., 1911, *8*, 189.
Hayhurst, E. R.: Occupational Brass Poisoning: Brass Founder's Ague. Tr. 15th Internat. Cong. Hyg. and Demog., 1912. Washington, Govt. Printing Office, 1913, *3*, Part 2, 764.
Hayhurst, E. R.: A Survey of Industrial Health-Hazards and Occupational Diseases in Ohio. Columbus, Ohio State Board of Health, Feb., 1915, pp. 132-135, 150.
Hayhurst, E. R.: Occupational Brass Poisoning: Brass-Founder's Ague. Am. Jour. Med. Sc., 1913, N. S. *145*, 723.
Hayhurst, E. R.: Brass, Copper (?), and Zinc Poisoning. Diseases of Occupation and Vocational Hygiene by G. M. Kober and W. C. Hanson. Philadelphia, P. Blakiston's Sons & Co., 1916, p. 15.
78. Oliver, T.: Dangerous Trades. London, John Murray, 1902, p. 144.
Oliver, T.: Diseases of Occupation. New York, E. P. Dutton & Co., 1916, p. 220.
79. Riesman, D., and Boles, R. S.: "Spelter Chills." Am. Jour. Med. Sc., 1917, N. S. *153*, 376.
80. Lehmann, K. B.: Kurzes Lehrbuch der Arbeits- und Gewerbehygiene. Leipzig, S. Hirzel, 1919, p. 217.
81. Rost, E.: Das Zink vom physiologischen und toxikologischen Standpunkt. Ber. d. deutsch. pharm. Gesellsch., 1919, *29*, 39.
82. Rost, E.: Zur Kenntnis des Giessfiebers, mit besonderer Berücksichtigung der Ausscheidungsverhältnisse der aufgenommenen Metalle Zink und Kupfer. Arb. a. d. Reichsgsndhtsamte., 1920, *52*, 1.
83. Schlockow: Ueber ein eigenartiges Rückenmarksleiden der Zinkhüttenarbeiter. Deutsch. med. Wchnschr., 1879, *5*, 208, 221.
84. Tracinski: Die oberschlesische Zinkindustrie und ihr Einfluss auf die Gesundheit der Arbeiter. Deutsch. Vrtljschr. f. öffentl. Gsndhtspflege., 1888, *20*, 59.
85. Seiffert: Die Erkrankungen der Zinkhüttenarbeiter und hygienische Maassregeln dagegen. Deutsch. Vrtljschr. f. öffentl. Gsndhtspflege., 1897, *29*, 419.
86. Wutzdorff: Die im Zinkhüttenbetriebe beobachteten Gesundheitsschädigungen und die zu ihrer Verhütung erforderlichen Massnahmen. Arb. a. d. k. Gsndhtsamte., 1900, *17*, 441.
87. Frey: Die Zinkgewinnung im oberschlesischen Industriebezirk und ihre Hygiene seit Erlass der Bekanntmachung des Bundesrats betreffend die Einrichtung und den Betrieb der Zinkhütten vom 6. Februar 1900. Vrtljschr. f. gerichtl. Med., 1907, *33*, 165, 403.
88. Hogben, E.: Brass-Workers' Disease. Birmingham Med. Rev., 1887, *21*, 195.
89. Murray, W.: Chronic Brass Poisoning. Brit. Med. Jour., 1900, *1*, 1334.
90. Pietrowicz, S. R.: A Case of Brass Molder's Ague. Jour. Am. Med. Assn., 1904, *43*, 465.
91. Wells, P. V., and Gerke, R. H.: An Oscillation Method for Measuring the Size of Ultramicro-

scopic Particles. Jour. Am. Chem. Soc., 1919, *41*, 312.

92. Green, H.: A Photomicrographic Method for the Determination of Particle Size of Paint and Rubber Pigments. Jour. Franklin Inst., 1921, p. 637.
93. Katz, S. H., Longfellow, E. S., and Fieldner, A. C.: The Efficiency of the Palmer Apparatus for Determining Dust in Air. THIS JOUR., 1920-1921, *2*, 167.
94. Breyer, F. G.: Methods of Collecting Dust and Fume in the Zinc and Blast Furnace Industries. Informal address before the Portland Cement Assn., May 21, 1921. Reprinted in Jour. Am. Soc. Heating and Ventilating Engineers, 1922, *28*, 289.

BOOK REVIEWS

THE NEWER KNOWLEDGE OF NUTRITION. THE USE OF FOOD FOR THE PRESERVATION OF VITALITY AND HEALTH. By *E. V. McCollum*, Ph.D., Sc.D., Professor of Chemical Hygiene in the School of Hygiene and Public Health, of the Johns Hopkins University, Baltimore, Md. Cloth. Second Edition. Pp. 449 with preface, table of contents, illustrations, and index. New York: The Macmillan Company, 1922.

THE average scientific man views with gratification a book which satisfactorily summarizes a vast amount of literature. Dr. McCollum has collected the most recent material on amino acid, inorganic salt, and vitamine needs, and has sorted, discussed and judged it. Everyone scientifically interested in metabolism should read this book, for it completes Lusk's "Science of Nutrition," and therefore furnishes a thorough summary of the hard-worked field of metabolism.

The book is not a textbook; the style is too chatty, and the evidence too detailed. A history of the development of the subject of nutrition is first presented, showing how ideas have crystallized and present theories developed. The new biologic methods for the analysis of foodstuffs, by which individual proteins of foods are tested on animals for their efficiency in producing growth and health, are thoroughly described. Equally as essential as the caloric content of foodstuffs —in regard to their physiologic effects—are vitamines and well-balanced variations in foods.

In a chapter on rickets, Dr. McCollum states that three dietary factors are concerned primarily in the development and normal metabolism of the skeletal tissues: phosphorus, calcium and vitamines. A contribution of great importance in this connection is the recent discovery by McCollum and others that "the ratio between the concentration of calcium and of phosphorus in the diet may, within certain limits, be of greater significance to the welfare of an animal than the absolute amounts of these substances which the diet contains."

Thus a very interesting, relatively new field of science is well epitomized. The statements made are based on experimental work; the book is replete with references. In addition to its scientific value, the book is a source of real pleasure.—*J. C. Aub.*